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# THE EFFECTS OF TURBULATORS ON FLOW PATTERNS AND PRESSURE LOSSES IN TWO-PHASE FLUID FLOW

A THESIS

Presented to

the Faculty of the Graduate Division

By

John Watson Parrott

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THE EFFECTS OF TURBULATORS ON FLOW PATTERNS AND PRESSURE LOSSES IN TWO-PHASE FLUID FLOW

APPROVED:

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TABLE OF CONTENTS

# LIST OF TABLES

LIST OF TABLES (Continued)

Table Page

LIST OF TABLES (Concluded)

Table | Page

# LIST OF FIGURES

LIST OF FIGURES (Concluded)

# NOMENCLATURE

| | |
|---|---|
| $A$ | cross-sectional flow area of pipe, ft.$^2$ |
| $D$ | inside diameter of pipe, ft. |
| $f$ | friction factor as defined by Nikuradse equation, dimensionless |
| $f_G$ | superficial friction factor for gas phase calculated from superficial Reynolds number for gas phase, dimensionless |
| $f_L$ | superficial friction factor for liquid phase calculated from superficial Reynolds number for liquid phase, dimensionless |
| $g_C$ | conversion factor, 32.17 ft. lb. mass/sec.$^2$ lb. force |
| $\ell$ | length or equivalent length, ft. |
| $P_{avg}$ | average pressure in test section, psia |
| $P_1$ | pressure at upstream end of test section, psig |
| $P_G$ | gas pressure at gas rotameter, psig |
| $Q_G$ | gas flow rate as read from calibration curve for gas rotameter before correcting for variation from standard conditions, CFM |
| $Q_L$ | volumetric flow rate of liquid, GPM |
| $Re_G$ | superficial Reynolds number for gas phase based on inside diameter of pipe, dimensionless |
| $Re_L$ | superficial Reynolds number for liquid phase based on inside diameter of pipe, dimensionless |
| $T_G$ | temperature of gas phase, °C |
| $T_L$ | temperature of liquid phase, °C |
| $u_G$ | superficial velocity of gas based on inside pipe diameter, ft./sec. |
| $u_L$ | superficial velocity of liquid based on inside pipe diameter, ft./sec. |

| | |
|---|---|
| $W_G$ | gas flow rate, lb. mass/sec. |
| $W_L$ | liquid flow rate, lb. mass/sec. |
| $X^2$ | the ratio of the pressure drop for the flow of liquid alone to the pressure drop for the flow of the gas alone, dimensionless |
| $\mu_G$ | viscosity of gas phase, lb. mass/ft. sec. |
| $\mu_L$ | viscosity of liquid phase, lb. mass/ft. sec. |
| $\rho_G$ | density of the gas at one atmosphere pressure and 70° F, lb. mass/ft.$^3$ |
| $\phi^2_{LTT}$ | parameter used by Lockhart and Martinelli (see reference 1), the ratio of the two-phase pressure drop per unit length to the pressure drop per unit length of the liquid phase (subscript L) flowing alone in the pipe, dimensionless. The subscript TT denotes that both the liquid and gas phases are in the region of turbulent flow as defined in reference (1) |
| $\psi$ | single-phase equivalent length multiplying factor used by Sharp (reference 2) and Gossage (reference 3), dimensionless |
| $\Delta P_{exp}$ | experimental pressure drop, in. Hg, or psi, as designated |
| $\left(\frac{\Delta P}{\Delta l}\right)_{TP}$ | two-phase pressure drop per unit length calculated from correlation of Lockhart and Martinelli (1), psi/ft. |
| $\frac{\epsilon}{D}$ | relative roughness of pipe, dimensionless |

SUBSCRIPTS

| | |
|---|---|
| L | liquid |
| G | gas |
| T | turbulator |
| P | pipe |
| TP | two-phase |

# ABBREVIATIONS OF FLOW PATTERNS

| | |
|---|---|
| st. | stratified |
| w. | wave |
| p. | plug |
| s. a. | semi-annular |
| a. | annular |
| f. | frothy |

Combinations of flow patterns are indicated by combining the abbreviations for the individual flow patterns with a hyphen between them, e.g., s.-a. is the abbreviation for slug-annular flow.

## SUMMARY

One of the basic phenomena of two-phase gas-liquid flow is the existence of different types of flow patterns in the fluid system, the actual type of flow pattern present depending largely upon the ratio of the gas flow rate to the liquid flow rate. The type of flow pattern that exists in a two-phase flow system exerts an influence on the pressure drop in the system, the performance of equipment such as pumps and compressors within the system, and presumably on the heat and mass transfer coefficients for the system. It seemed profitable, therefore, to investigate the effect on flow patterns of placing different types of turbulators in the flow system.

The air-water system was chosen for study in this experimental program. Different types of turbulators, such as wire screens, orifice plates, packed sections, and spiral coils, were placed in a glass pipe test section. Various combinations of air and water rates were systematically run through the test section with one of the turbulators placed in the section. The flow patterns existing upstream and downstream of of the turbulator were observed and recorded, along with the pressure drop across the test section and other pertinent information. This procedure was repeated for each one of the turbulators investigated.

It was found that most of the turbulators employed caused temporary changes in the flow patterns existing in the system. The most common effect observed was the changing of a slugging flow pattern to an

annular pattern. The annular flow pattern was usually maintained from one to five feet downstream of the turbulator. It was found that the turbulators which created annular flow patterns which were maintained for relatively long distances downstream also caused relatively large pressure drops across the test section for fixed rates of air and water flow. The correlation proposed by Gossage (3) for predicting the pressure drops across valves during two-phase flow was found to work satisfactorily in predicting the pressure drops caused by the turbulators when the equivalent lengths of the turbulators for single phase flow were known and when the values of $X^2$ were greater than about three.

# CHAPTER I

## INTRODUCTION

The purpose of this study was to investigate the effect of turbulators on the flow patterns existing in two-phase, gas-liquid flow in horizontal pipes. The term "turbulator" as used in this paper, will be defined to be a physical obstruction, constriction, or mixing device placed in the interior of a system in which two-phase, gas-liquid flow occurs for the purpose of producing a change in the flow pattern of the fluid system.

The recent development of interest in two-phase flow problems is due not only to the challenging nature of the problems encountered but also to the many opportunities for applying any new knowledge gained to a variety of industrial and commercial operations. Some of the more common of these operations involve evaporation, boiling, flashing, condensation, and evolution of dissolved gases. These operations occur in many of the unit operations of chemical engineering, in petroleum production and refining, in the generation of steam for power production, and in the flow of fuel in aircraft fuel systems at high altitudes.

An examination of the literature has indicated that, in practically all investigations to date, air or natural gas has been used as the gas phase; and water, benzene, or hydrocarbon fuels or oils have been used as the liquid phase. Most of the information available (1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 13, 14) is for co-current flow of the two phases in straight horizontal or vertical cylindrical ducts, ranging in size from capillary tubes to two inch pipes. Work has been done on systems with and without mass transfer between phases. Summaries of this work are given in references(11) and (12).

An important characteristic found in gas-liquid flow systems is the existence of various flow patterns. The change from one flow pattern to the next does not usually occur with any definite transition point. These flow patterns depend on the relative amounts and velocities of the phases; the nature of the phases, i. e., viscosity, density, etc.; the geometry of the piping; entrance effects; and external vibrations and pulsations.

When starting with a horizontal pipe running full of liquid and adding increasing amounts of a gaseous phase, the following seven flow patterns have been observed in two-phase flow:

1) bubble flow, in which bubbles of the gas move along the top of the pipe at approximately the same velocity as the liquid;

2) stratified flow, in which the gas occupies the upper portion and the liquid the lower portion of the pipe with a smooth interface between the phases;

3) wave flow, in which the interface is disturbed by waves;

4) plug flow, in which large plugs of vapor and liquid move along the pipe length with the liquid phase controlling;

5) slug flow, in which rapidly moving slugs of liquid move along the pipe length with the gas phase controlling;

6) annular flow, in which a high velocity gas stream flowing in a central core causes the liquid phase to assume an annular flow channel against the pipe wall; and

7) mist flow, in which the liquid drops are distributed throughout the continuous gas phase.

For clarification and future reference the flow patterns observed during the experimental program are plotted as a function of the air and water rates in Fig. 1. Illustrations of some of the flow patterns encountered during this study are shown in Fig. 2.

It has been found by a number of investigators (4, 6, 14) that the pressure drop in a two-phase system is a function of the type of flow pattern prevailing in the system as well as the usual variables such as mass rate of flow, density, Reynolds number, etc. This is evidenced by the fact that no single generalized correlation has proven successful in predicting pressure drops for all types of flow patterns. Ward, Goglia, and co-workers (13) have found that the performance of pumps in jet aircraft fuel systems where two-phase flow exists depends on the type of flow pattern existing in the fuel lines as well as on the pressure, temperature, and volumetric ratio of vapor to liquid flowing in the line. Levy (14) has indicated from theoretical considerations that the rate of heat transfer in a two-phase fluid system is dependent upon the flow pattern in the system. Presumably, mass transfer rates would also be influenced by flow pattern types in a two-phase system.

From the above discussion it can be seen that there are numerous instances in which it might be desirable to produce a specific flow

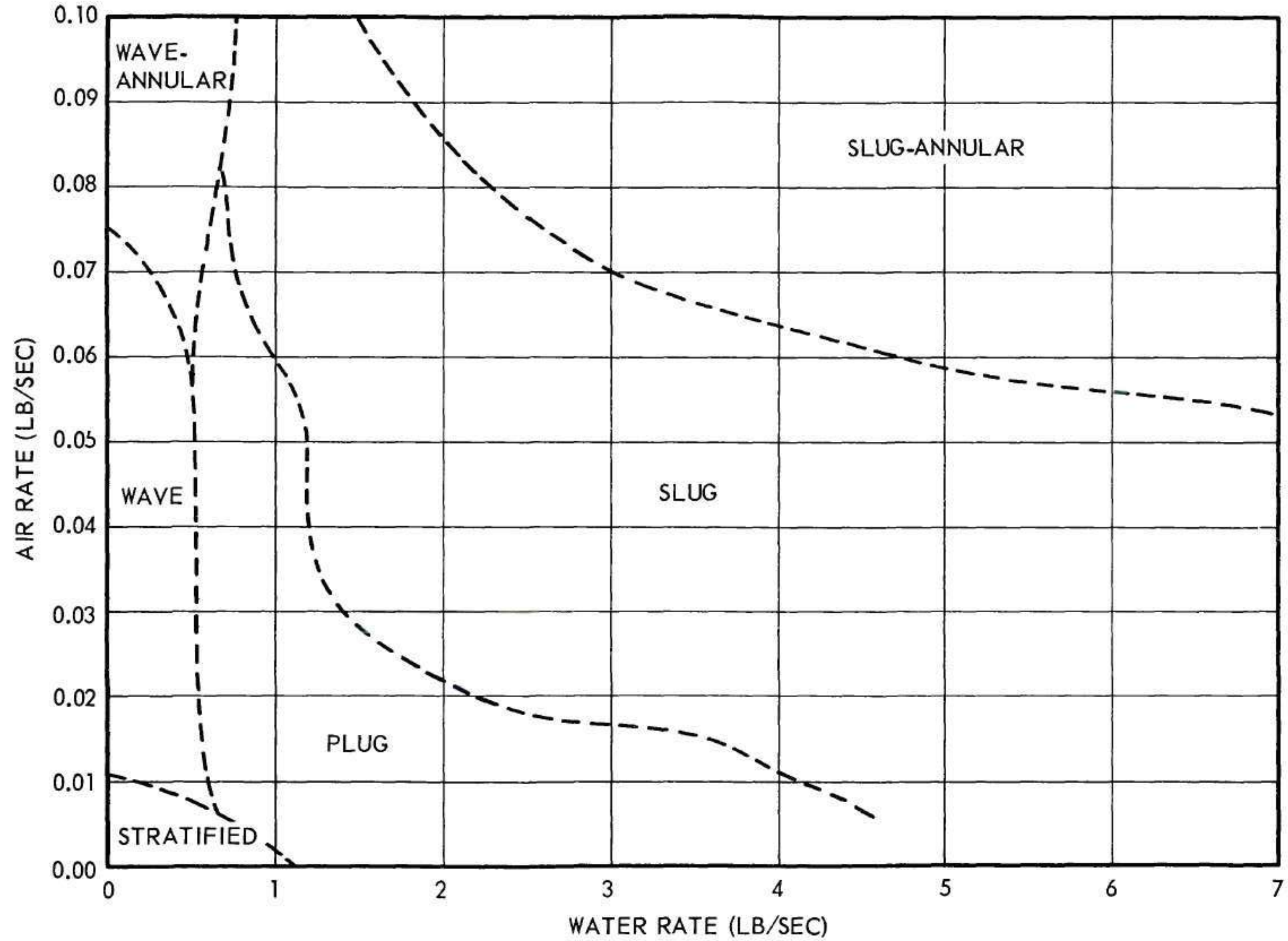



Figure 1. Observed Flow Patterns for Co-Current Flow of Air-Water Mixtures in 1-1/2-Inch Pipe as a Function of Air and Water Mass Flow Rates.

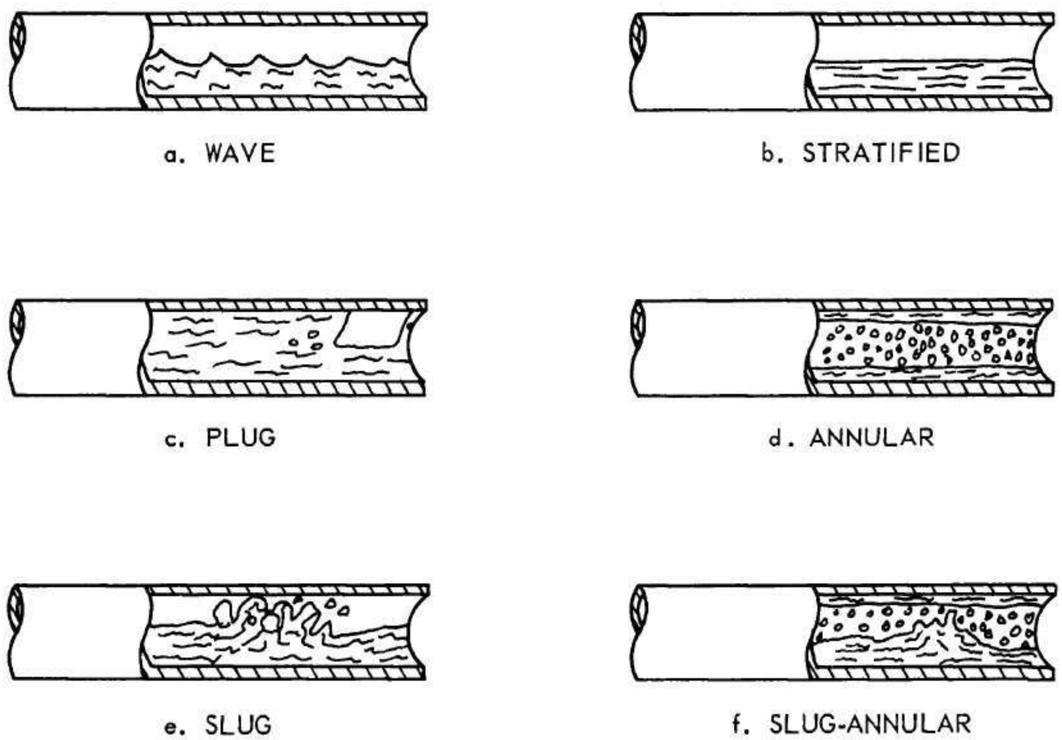



Figure 2. Flow Patterns.

pattern in a given system. Therefore, the present study of the effects of turbulators on flow patterns was undertaken. In addition to determining the effect of turbulators on flow patterns, the pressure drops caused by each turbulator tested were measured at various air and water rates. These pressure drops were then compared with those predicted by using the correlation of Gossage (3) to evaluate the equivalent length of the turbulator in two-phase flow from the value of its equivalent length for single phase flow. The following sections describe in detail how these studies were carried out and the results that were obtained from them.

# CHAPTER II

## INSTRUMENTATION AND EQUIPMENT

The apparatus used in this experiment was essentially the same as that used by Sharp (2) in his work on predicting pressure drops across valves and fittings during two-phase flow. Schematic flow diagrams are shown in Figs. 3 and 4. Photographs of portions of the equipment are shown in Figs. 5 through 9. Drawings and photographs of some of the various turbulators which were used are shown in Figs. 10 and 11.

The apparatus consisted of the following components: separate devices for metering the air and water phases into the test system, which allowed also for the determination of the temperatures and pressures of the separate phases; a section of pipe in which the two phases were mixed and a definite flow pattern established; a test section consisting of the turbulator to be studied and sufficient glass piping on either side of the turbulator to allow the observation of the flow patterns upstream and downstream of the turbulator; pressure measuring instruments which permitted the determination of the pressure drop across the test section and of the average pressure in the test section; and a device for separating the two phases after they had passed through the test section, thus allowing the water to be continuously recycled. The following paragraphs contain a more detailed discussion of the individual components of the apparatus and also a description of the various individual turbulators which were used.

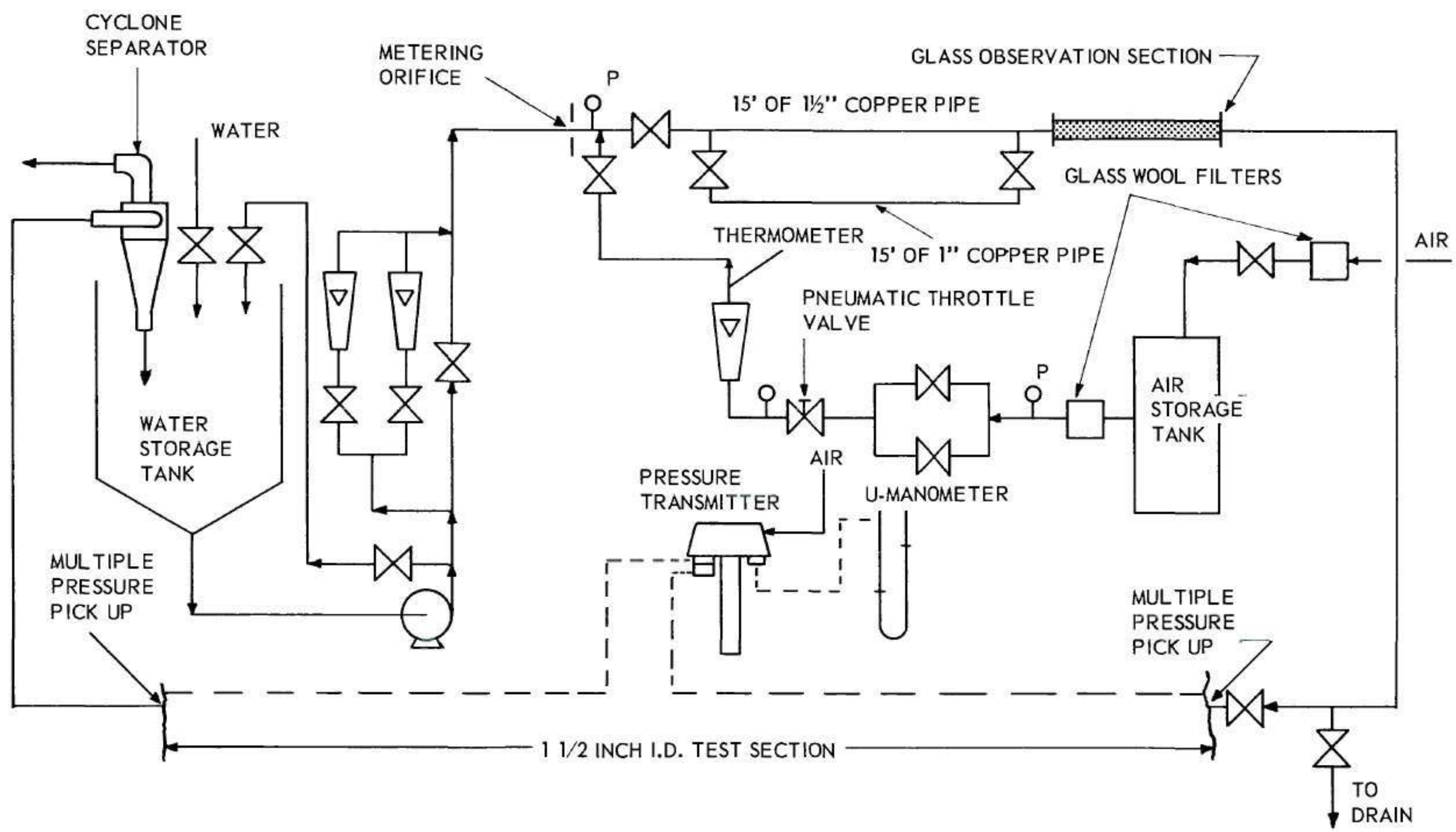



Figure 3. Schematic Diagram of Experimental Apparatus.

NOTE: ALL IRON PIPE IN THE TEST SECTION IS 1-1/2 INCH SCHEDULE 80 IRON PIPE.
ALL GLASS PIPE FOR VISUAL OBSERVATION IN THE TEST SECTION IS 1-1/2 INCH PYREX DOUBLE TOUGH GLASS PIPE.

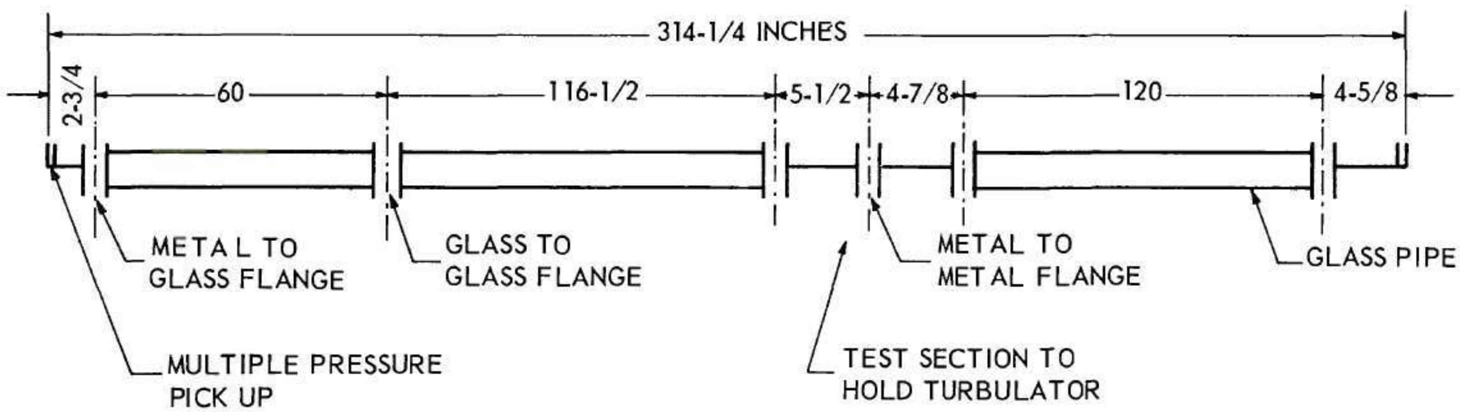



Figure 4. Piping Diagram of Test Section.

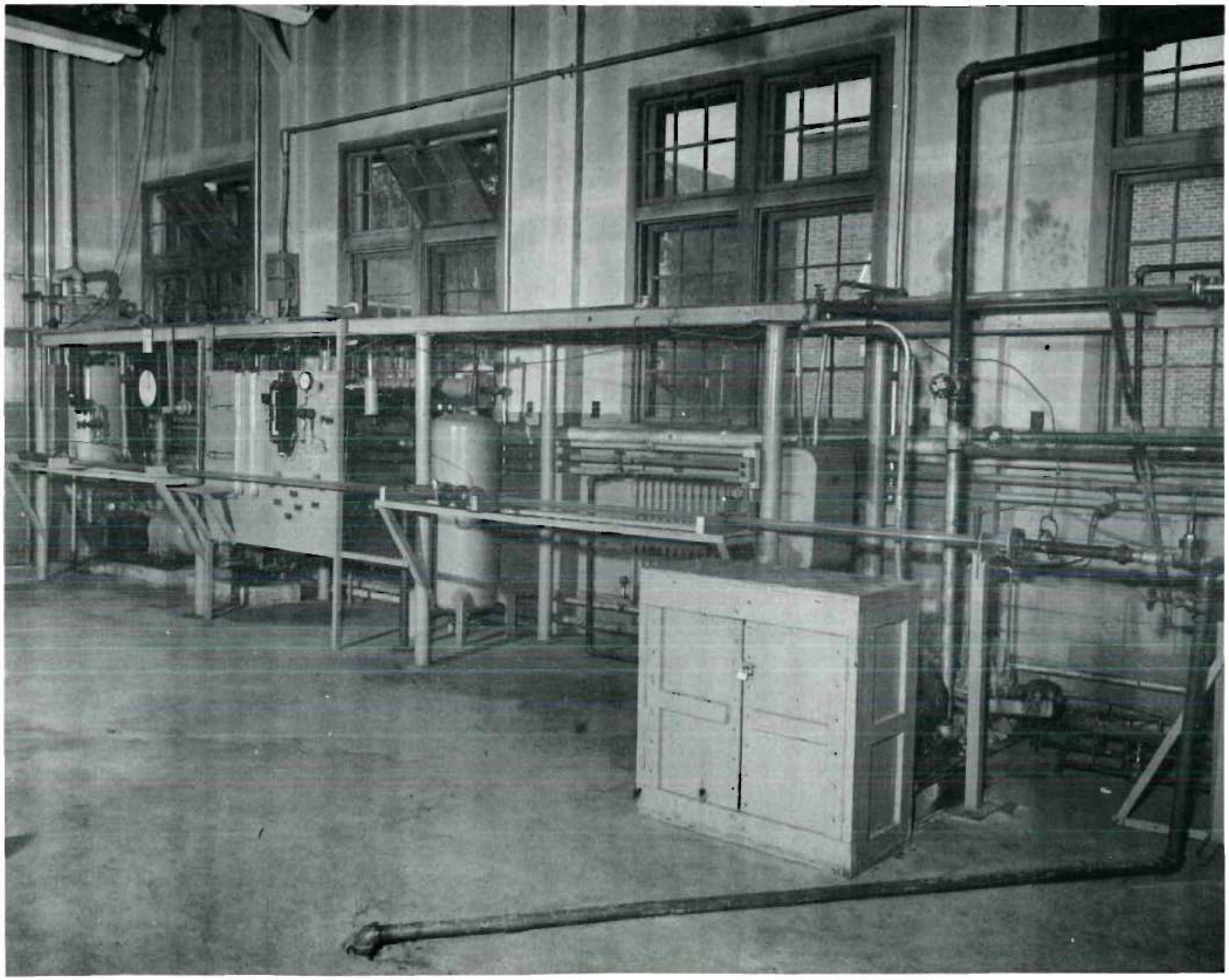


Figure 5. Experimental Apparatus.

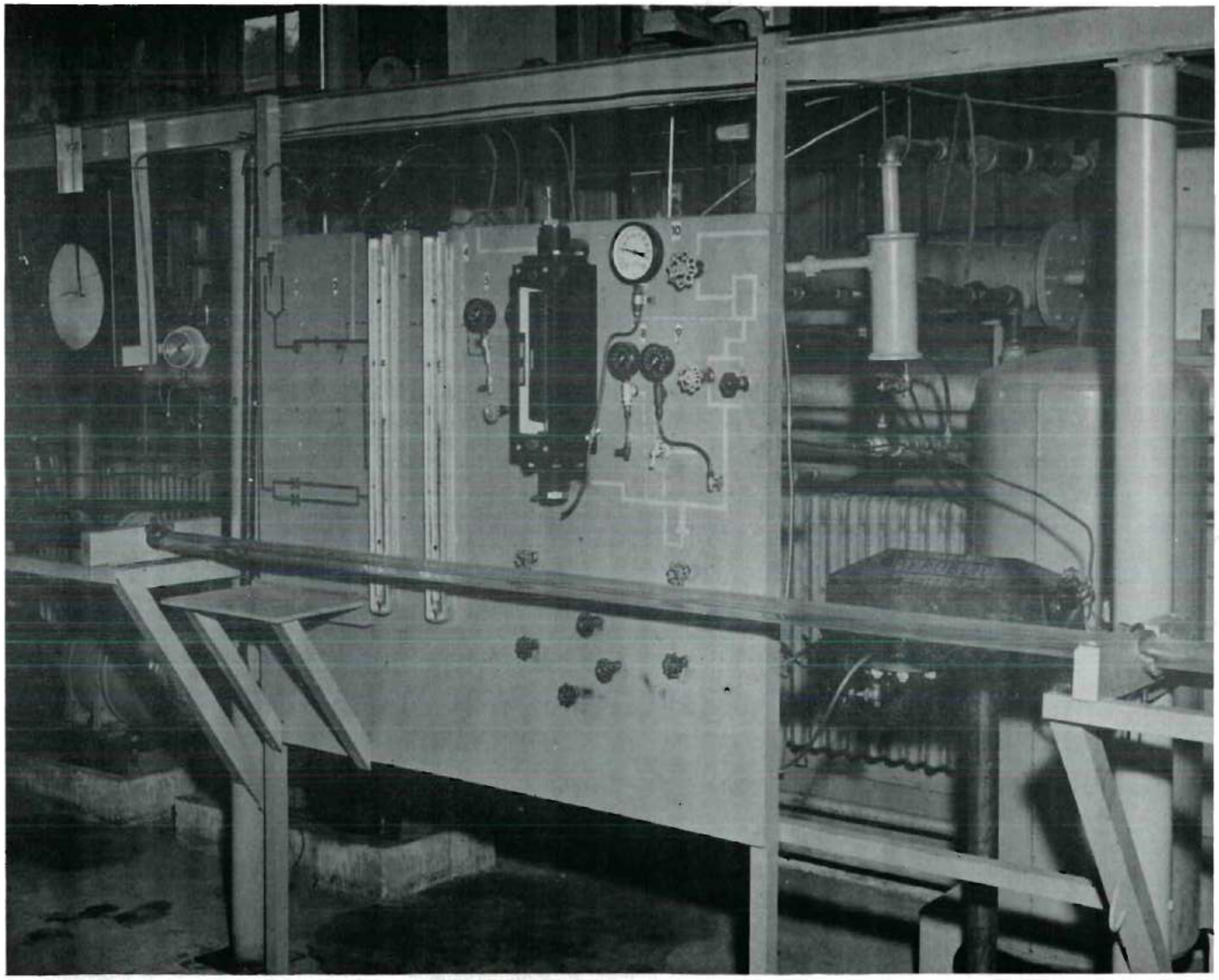


Figure 6. Control Panel.

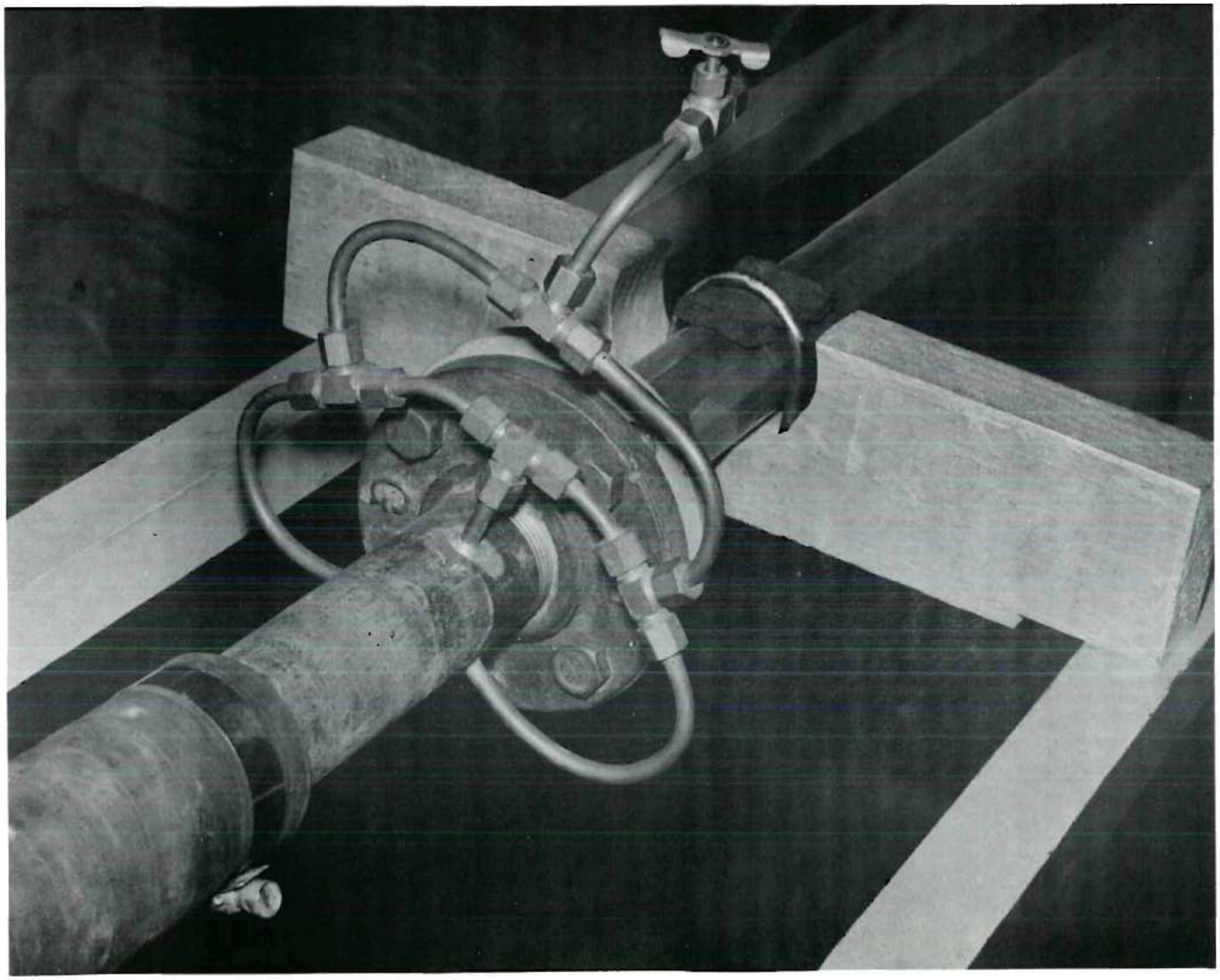


Figure 7. Pressure Pick-Up Device.

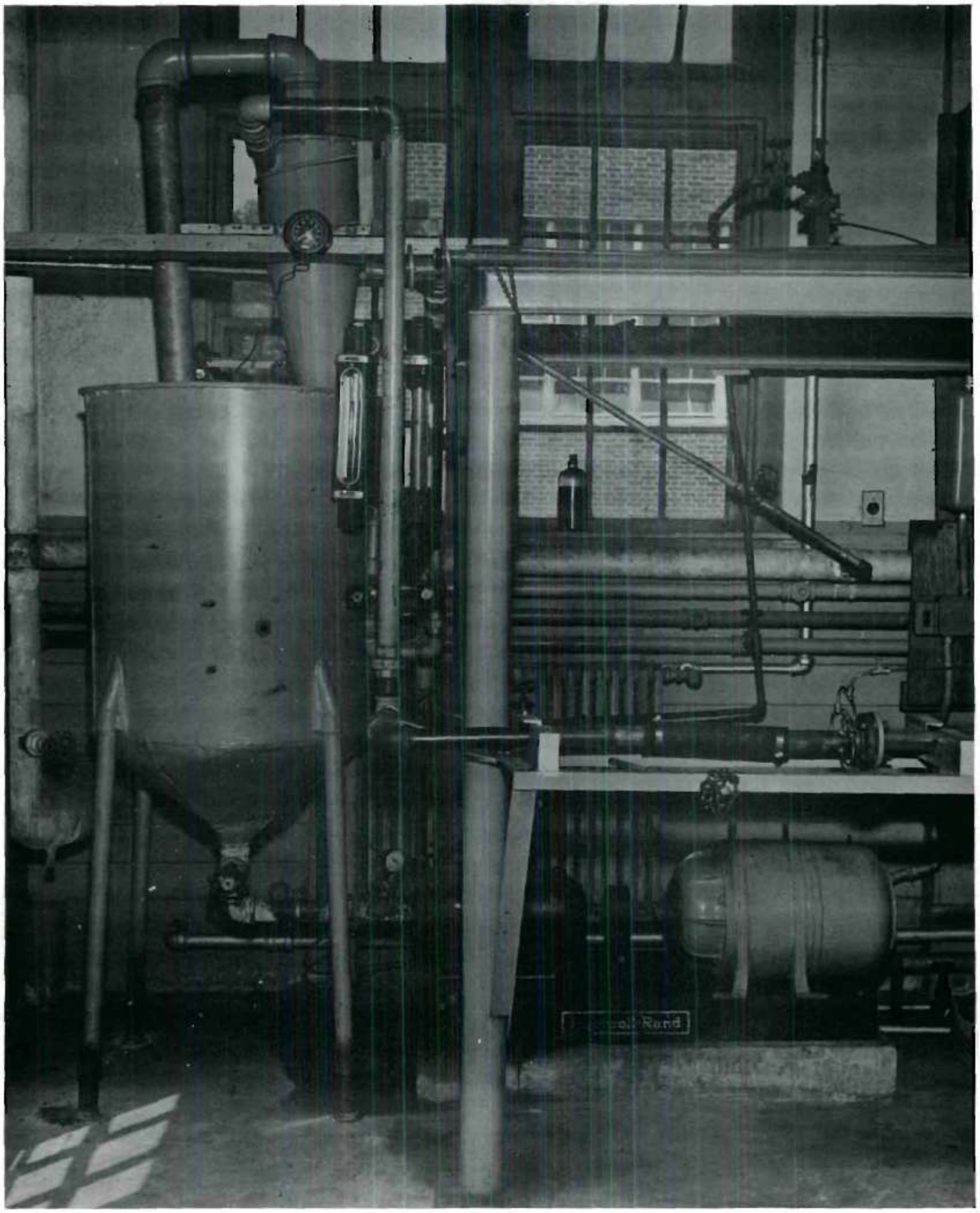


Figure 8. Water Storage with Pump and Cyclone Separator.

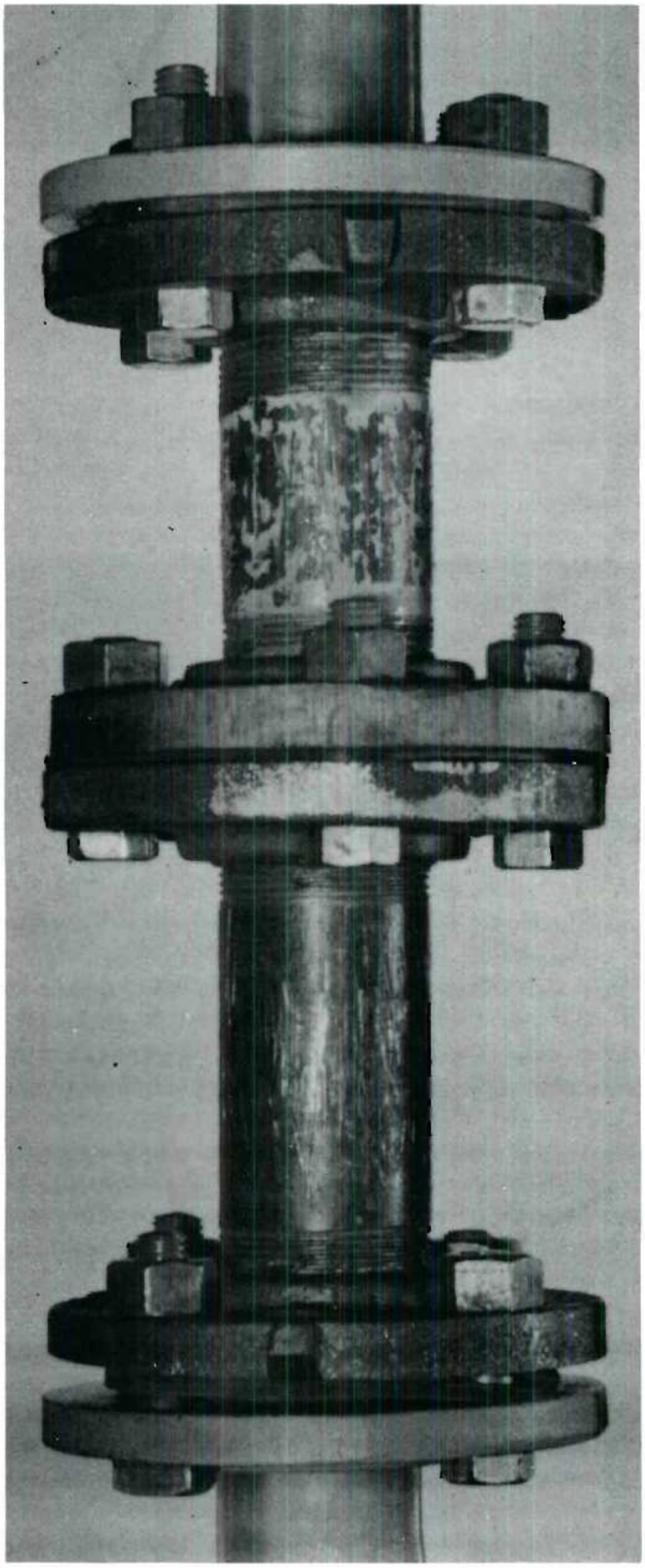
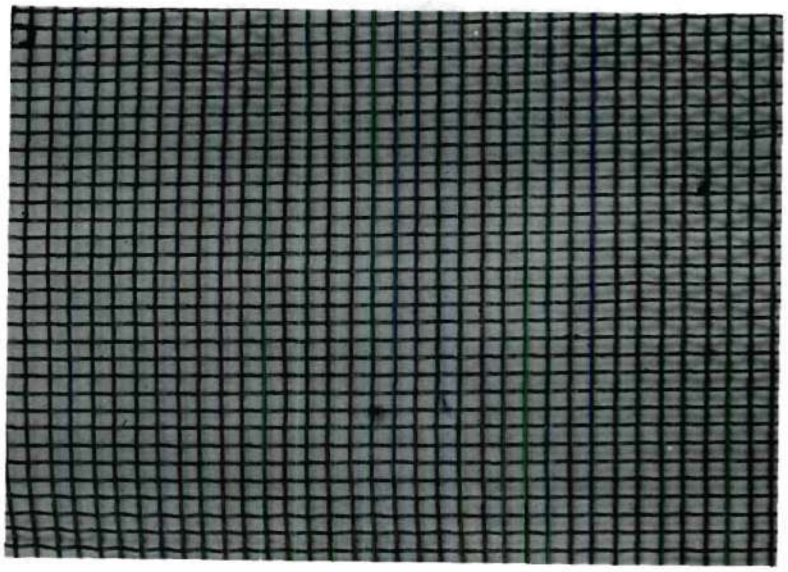
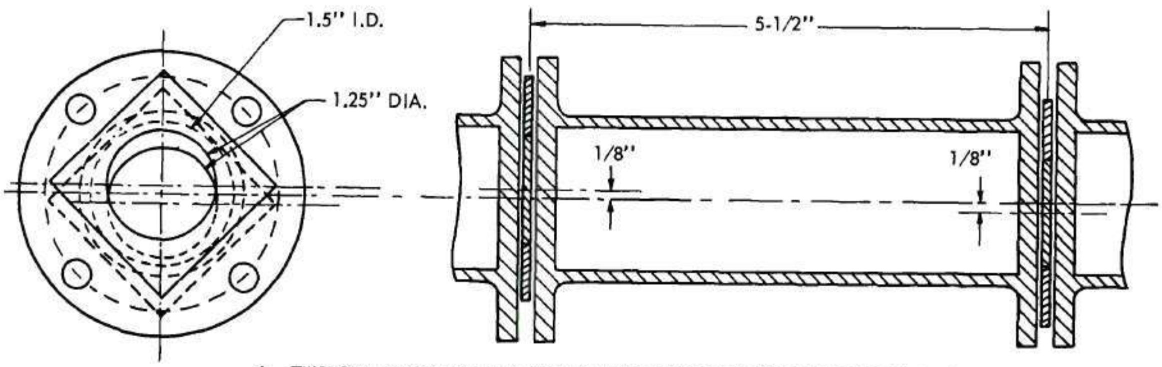


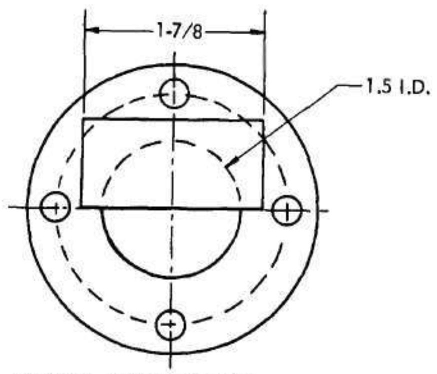
Figure 9. Turbulator Section.



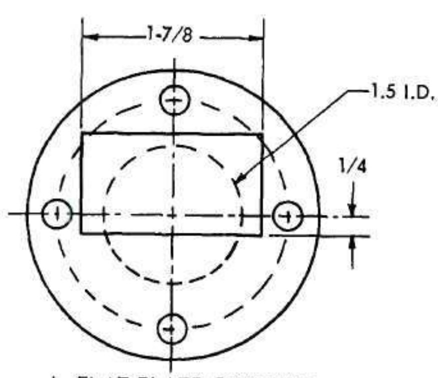
a. WIRE SCREEN FOR TURBULATOR




b. TWO OFF-CENTER 1-1/4 INCH DIAMETER ORIFICES FOR TURBULATOR

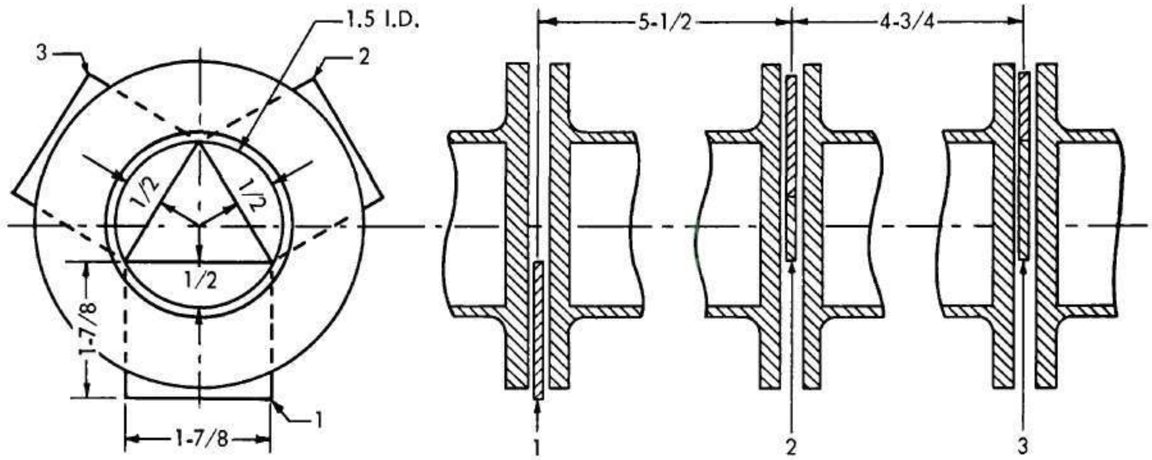



c. FLAT PLATE COVERING UPPER HALF OF PIPE DIAMETER FOR TURBULATOR

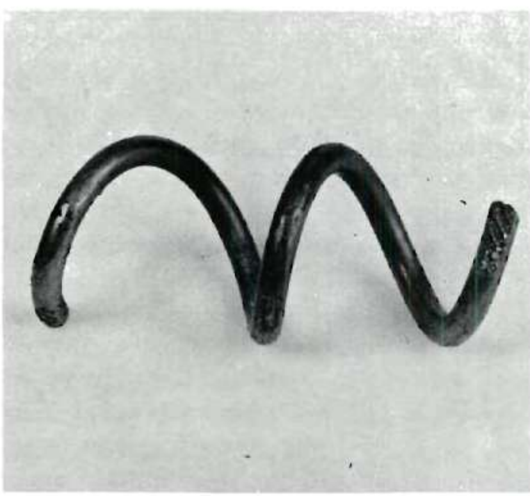



d. FLAT PLATE COVERING UPPER TWO-THIRDS OF PIPE DIAMETER FOR TURBULATOR

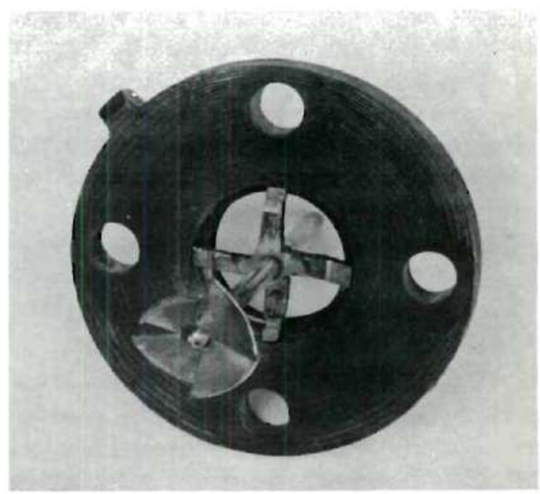
Figure 10. Turbulators.




a. SEGMENTED ORIFICE FOR TURBULATOR



b. SPIRAL COIL FOR TURBULATOR



c. PROPELLER FOR TURBULATOR

Figure 11. Turbulators.

The Air Supply System.--The air for this experiment was supplied by an Ingersoll-Rand 50 CFM compressor. The compressed air was brought into an eight cubic foot storage tank at a pressure between 90 and 120 psig. Before entering and leaving the storage tank, the air was passed through two glass wool filters to eliminate any foreign material that might be present in the air stream. The flow of air from the storage tank was regulated by two needle valves of different size which served as fine and coarse adjustments. After passing through the needle valves, the air flowed through a 3/8-inch Klipfel diaphragm type reducing valve operated pneumatically. This valve allowed the line pressure to be reduced from approximately 100 psig to any desired value between 0 and 60 psig. After being throttled, the air flowed through a Schutte and Koerting model 18200 Safeguard Rotameter fitted with an aluminum number 61-K rotor. The calibration curve for this instrument was furnished by the manufacturer. The pressure and temperature of the air flowing through the rotameter were measured with a pressure gauge calibrated in this laboratory and a mercury thermometer. The air flowed from the rotameter into the test system through a piece of 3/8-inch standard iron pipe, which was teed at 90 degrees to the 1 1/2-inch water supply line. The end of the 3/8-inch pipe, after being brazed into the water pipe, was carefully rounded so that it would conform to the interior surface of the water line. The air supply control panel is shown in Fig. 6.

The Water Supply System.--The water supply system consisted of the following elements: a conical bottom storage tank with a volume of about 125 gallons; an Ingersoll-Rand 1 CORVNL pump having a capacity of 75 GPM against a head of 120 feet of water; two rotameters mounted in parallel for measurement of flow rates less than 14 GPM; and a rotameter bypass line equipped with a metering orifice calibrated in this laboratory for measurement of water flow rates between 14 and 50 GPM. A mercury thermometer was placed in the water storage tank to record the temperature of the liquid phase.

The Mixing Section.--The mixing section consisted of 15 feet of 1 1/2-inch copper pipe flanged to a 5 foot section of Pyrex Double Tough 1 1/2-inch glass pipe, two Crane Company number 1001 long sweep 90 degree drainage elbows, and several additional feet of 1 1/2-inch schedule 80 iron pipe which served to connect the mixing section with the test section.

The Test Section.--A detailed drawing of the piping layout in the test section is shown in Fig. 4. Near the center of the test section were two short pieces of 1 1/2-inch schedule 80 iron pipe, each piece being about 5 inches long and the two pieces hang flanged together. The various turbulators were held in position by these two pieces of pipe in ways that will be described later. Upstream of the two pieces of iron pipe was a 10 foot section of Pyrex Double Tough 1 1/2-inch glass pipe, flanged on each end to a section of iron pipe. Four and five-eighths inches upstream of this piece of glass pipe the upstream pressure pick-up was placed. Downstream of the two short pieces of iron pipe two lengths of 1 1/2-inch glass pipe were placed. The two pieces of glass pipe, one piece 10 feet in length and the other piece 5 feet long, were flanged together; and the entire glass section was flanged at each end to a section of 1 1/2-inch iron pipe. The downstream pressure pick-up was put in the iron pipe 2 3/4 inches from where the iron pipe was flanged to the glass section. The two glass sections allowed the observance of the flow patterns existing in the pipe before and after the fluid passed through the turbulator section.

The Pressure Measuring Instruments.--The pressure drop across the test section was measured using two multiple pressure tap devices, one of which is shown in Fig. 7. The pressure impulses from these tap devices were transmitted through water-filled 3/16-inch copper tubing to a Republic pneumatic differential pressure transmitter. This device was calibrated in position against known water pressures before use. The output air signal from this instrument was read on a 30 inch mercury U-tube manometer. A Bourdon type pressure gauge calibrated in these laboratories was connected to the upstream pressure pick-up to allow calculation of the average pressure in the test section.

The Phase Separation Device.--A small cyclone separator shown in Fig. 8 was used for separation of the air and water phases after they had passed through the test section. The water leaving the cyclone dropped into the storage tank and was recycled through the system.

Turbulators.--Twelve different turbulators were investigated during this study. Drawings and photographs of some of these turbulators are shown in Figs. 10 and 11. A verbal description of the separate turbulators is given below.

Turbulator I was a wire screen with 144 openings per square inch. It was placed between the two flanges joining the two short pieces of iron pipe in the center of the test section and covered the entire cross-sectional area of the pipe.

Turbulator II was a Crane 200-pound bronze 1 1/2-inch globe valve, full open. The valve was placed in the center of the test section between the two short pieces of iron pipe.

Turbulator III was the same valve as described above, half open.

Turbulator IV was a 0.05 inch brass plate with a 3/4-inch orifice in the center of the plate. The plate was installed between the two metal to metal flanges mentioned above.

Turbulator V was similar to the one described above except that the orifice size was increased to 1 1/4 inches.

Turbulator VI consisted of two 1 1/4-inch orifices spaced 5 1/2 inches apart in the center of the test section. One orifice was placed between the two flanges at the upstream glass to metal connection with the center line of the orifice 1/8 inch below the center line of the pipe. The other orifice was installed between the metal to metal flanges with its center line 1/8 inch above the center line of the pipe.

Turbulator VII was a 0.05 inch brass plate placed between the two metal to metal flanges, the bottom edge of the plate coinciding with the center line of the pipe.

Turbulator VIII was the same brass plate placed between the flanges so that its lower edge was parallel to and 1/4-inch below the center line of the pipe.

Turbulator IX was a segmented triangular orifice. It consisted of three 0.05 inch brass plates placed between flanges and spaced approximately 5 inches apart. The edges of the plates protruded 1/2 inch into the interior of the pipe and were positioned in such a way that the projections of the three edges in a plane perpendicular to the axis of the pipe formed an equilateral triangle whose vertices fell on the inside circumference of the pipe. For a clearer description of this turbulator, refer to Fig. 11a.

Turbulator X was a 4 inch long spiral coil, formed from a 1/4-inch steel rod, with a 2 inch pitch. The coil fitted tightly inside one of the short pieces of iron pipe in the center of the test section.

Turbulator XI was a four-bladed propeller, 1 1/4 inches in diameter, mounted on a 1/4-inch steel rod, on which the blade was free to rotate. The rod was in turn mounted on a brass spider which fit tightly into a 2 inch hole bored 3/8-inch deep into the face of one of the metal flanges.

Turbulator XII was a 6 inch section of iron pipe packed with 1/2-inch Raschig rings. Two screen wires held the Raschig rings in the 6 inch section.

# CHAPTER III

## EXPERIMENTAL PROCEDURE

The first phase of the experimental program consisted of checking the apparatus and instruments in order to be sure that reliable results would be obtained. The instruments for measuring the water flow and those for determining the pressure drops across the test section were checked by allowing water to flow through the system at measured rates and observing the pressure drop reading corresponding to each water rate. These pressure drops were then compared to those calculated by using the standard friction factor-Reynolds number correlation. Next, the instruments for measuring the air pressures and flow rates were checked by allowing air and water to flow co-currently through the apparatus at measured rates and observing the pressure drop reading across the test section corresponding to each combination of air and water rates. These pressure drop readings were then compared to those calculated from the Lockhart and Martinelli (1) correlation.

The next phase of the experimental program was the performance of test runs with one of the turbulators placed in the test section. With a given turbulator in place in the test section, measurements were made at a numer of different water rates (usually seven) varying from 2 to 40 GPM. At each water rate several different air rates were run varying from about 0.01 to 0.10 pounds per second.

The operating procedure was essentially the same for the test runs on each turbulator. For a typical test run with a given turbulator in the test section the water rate was set at the initial value of 2 GPM, and the pressure taps were opened and filled with water. After all the air had been forced from the pressure tap lines, measurements were made at the water rate of 2 GPM. These measurements included the water rate, the water temperature, the pressure drop across the test section, and the gauge pressure at the upstream pressure tap. This procedure was repeated at different water rates up to 40 GPM. The water rate was then returned to a value of 2 GPM for the beginning of the two-phase runs. The air rate was set at an initial value of $Q_G$ equal to 8.5 CFM, and the air was forced into the mixing section at a pressure slightly above the pressure in the mixing section. The water rate was maintained at 2 GPM while measurements of pertinent variables were made and their values recorded. These variables were the water rate, water temperature, air rate, air temperature, air pressure, the pressure drop across the test section, and the gauge pressure at the upstream pressure tap. In addition to these variables, at each air rate the flow patterns upstream and downstream of the turbulator section were observed visually and recorded. These measurements were made at several different air rates for values of $Q_G$ betweeen 8.5 and 46.0 CFM, all at a constant water of 2 GPM. The air rate was then decreased to a value of $Q_G$ of 8.5 CFM, the water rate was increased to the next value; and a new group of data was obtained for the various air rates at a constant water rate. This procedure was repeated until the entire range of water rates had been covered. The turbulator was then removed from the test section, and a different one was installed. The complete experimental data obtained as described above are shown in Table 4.

# CHAPTER IV

## DISCUSSION OF RESULTS

The data and calculated results are presented in Tables 1 through 3 and in Figs. 12 through 14. The original data are on file in the School of Chemical Engineering of the Georgia Institute of Technology.

Water Runs with No Turbulator.--In order to test the accuracy of the instruments, some preliminary measurements were made of pressure drops during single-phase liquid flow for comparison with values obtained from the friction factor-Reynolds number correlation. Ignoring the values obtained at low flow rates, where accurate pressure drop measurements were not possible, the maximum deviation of the experimental data from the calculated values was +13 per cent, and the average deviation was +3 per cent. These discrepancies were probably due to the presence in the test section of six flanged connections and approximately one and a half feet of iron pipe which were included in the calculations as smooth pipe. While it would have been possible to compensate for these errors by adding the equivalent lengths of the flanges and iron pipe to the actual length of the test section, the magnitude of the error did not warrant making this refinement in the calculations. The results obtained from this part of the experimental work are included in Table 1.

Two-Phase Runs with No Turbulator.--In order to determine the applicability of the Lockhart and Martinelli (1) correlation to the particular experimental system that was investigated, a series of two-phase runs were

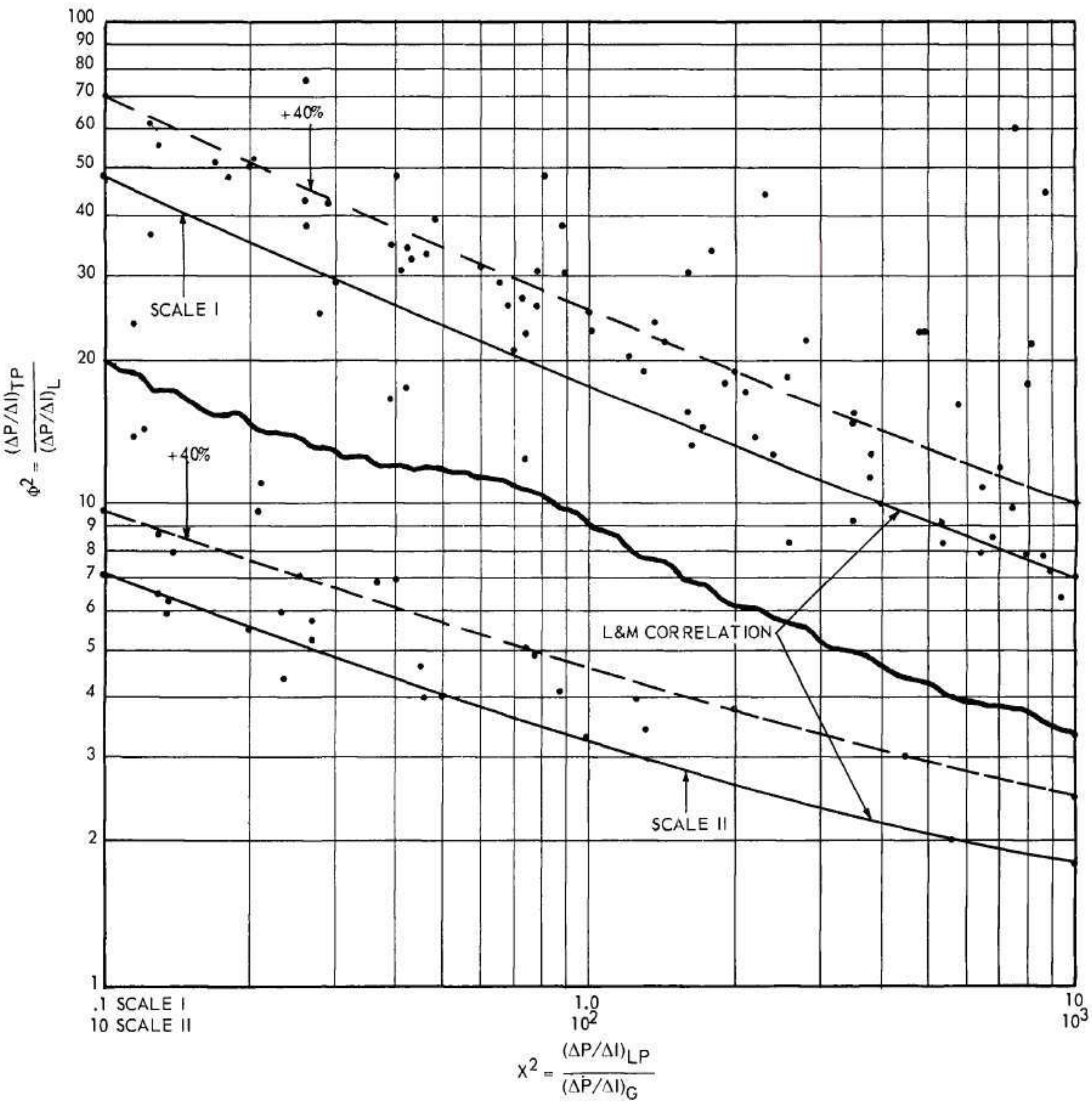



Figure 12. Comparison of Calibration Data on 314 Inch Straight Horizontal Section of 1-1/2 Inch Pyrex Double Tough Glass Pipe for Co-Current Turbulent - Turbulent Flow of Air and Water with Correlation of Lockhart and Martinelli.

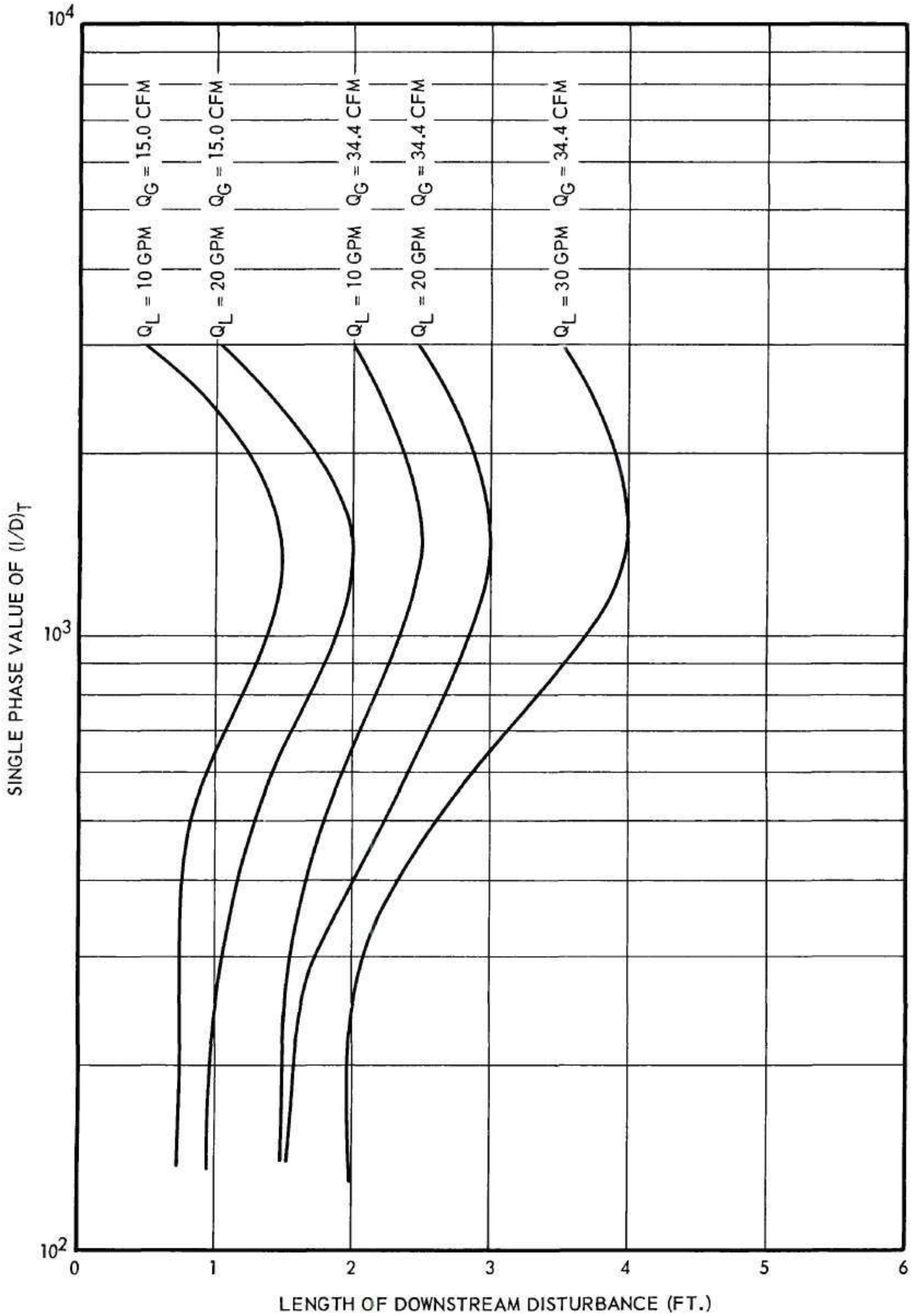



Figure 13. The Effect of Water and Air Flow Rates and Equivalent Lengths of Turbulators on the Duration of Transformed Flow Patterns.

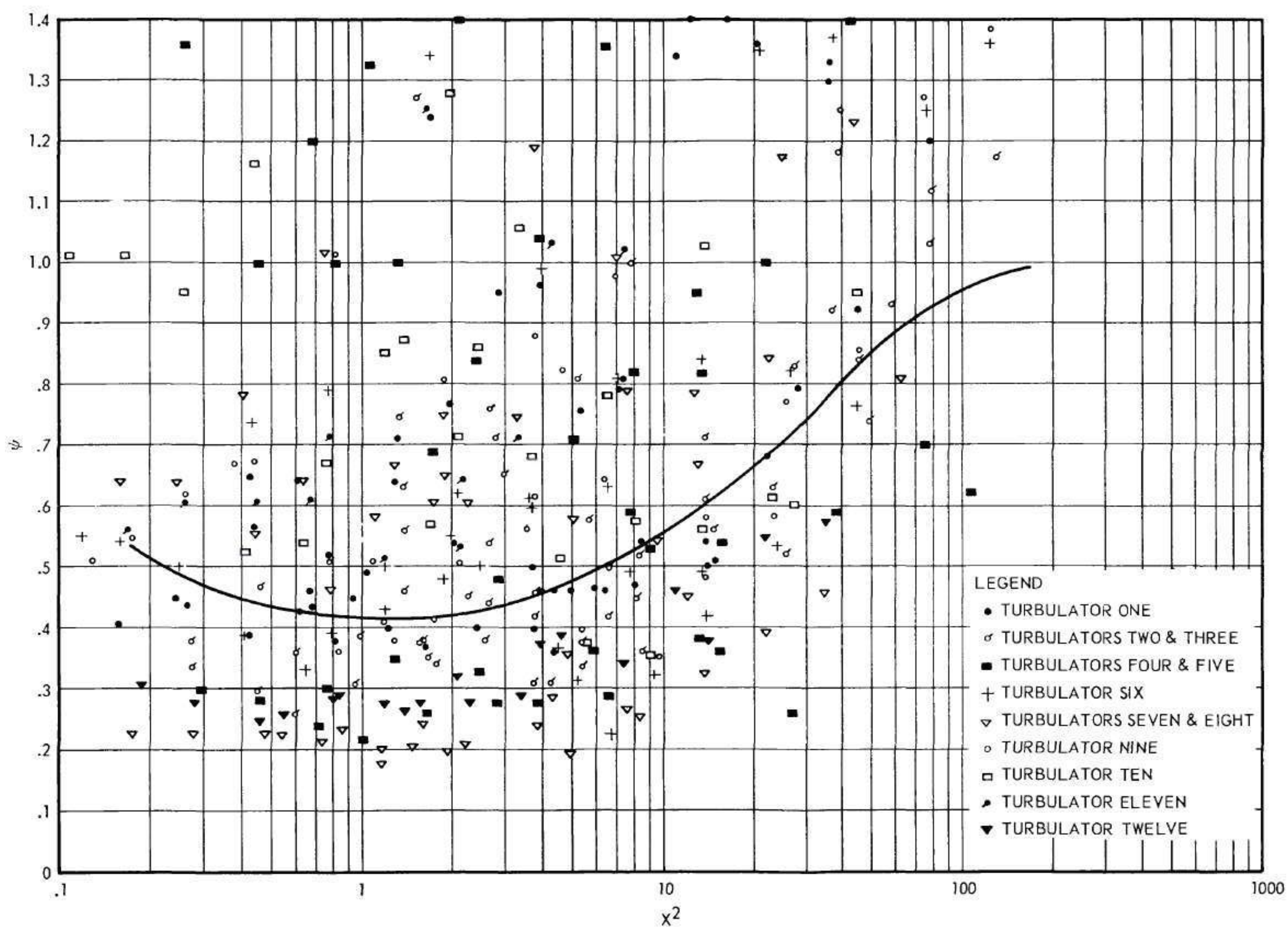



Figure 14. Experimental Values of $\psi$ versus $X^2$.

made with no turbulator in the test section. From measurements made during these runs values of $X^2$ and $\phi^2_{LTT}$ were obtained and compared with those given by Lockhart and Martinelli (1). This comparison is shown in Fig. 12. Approximately 75 per cent of the experimental points were found to fall within the range of accuracy which Lockhart and Martinelli have given for their correlation, i.e., ±40 per cent. Virtually all of the experimental points which fell outside the Lockhart and Martinelli correlation were in the region of plug flow, where erratic fluctuations in the manometer readings made pressure drop determinations extremely difficult. The experimental values of $\phi^2_{LTT}$ were on the average about 25 per cent greater than those on the correlation curve. Neglecting those points which were obtained for plug flow, the experimental points fell about 10 per cent above the curve of Lockhart and Martinelli. This same trend has been observed by Gossage (3). The data and results for this group of experimental runs is given in Table 2.

Two-Phase Runs with Turbulators.--The principal part of the experimental program consisted of making a series of two-phase runs with one of a number of turbulators in place in the test section and observing the effects of the turbulator on the flow pattern in the test section and on the pressure drop across the section. It was found that the turbulators had no appreciable effect on the flow pattern that existed in the upstream portion of the test section, but that they generally exerted a temporary influence on the downstream flow pattern. (Upstream refers to that portion of the test section upstream of the turbulator; downstream refers to that portion of the test section downstream of the turbulator.) The most common effect noted was the changing of a plug, slug, slug-annular, or a wave flow pattern to an annular pattern, which remained for one to several feet downstream of the turbulator. This effect was noticed for all turbulators except the wire gauze and the packed section. Almost no effect was obtained with the wire gauze, and the packed section tended to produce a frothy pattern from whatever flow pattern existed in the upstream portion of the test section. None of the turbulators produced any change in stratified flow-patterns. With all turbulators the flow patterns in the portion of the test section several feet downstream from the turbulator were identical to the upstream patterns. The length of the disturbance in the downstream flow pattern due to the presence of the turbulator in the test section depended primarily on the equivalent length of the turbulator used and on the mass rates of flow of the gas and liquid phases through the test section. An increase in either one of these factors caused an increase in the duration of the modified flow pattern caused by the turbulator. This relationship is shown in Fig. 13. It can be seen from Fig. 13 that a disturbed flow pattern could be maintained for a greater distance by using several turbulators, each having a small equivalent length, in series than by using one turbulator with a very large equivalent length. Of those turbulators which were tested in this study the ones which would be most useful in rectifying an undesirable flow pattern are: globe valve, full open; 1 1/4-inch orifice; two off center 1 1/4-inch orifices six inches apart; flat plate covering upper half pipe diameter; segmented orifice; and the spiral coil turbulator. The others that were tested either did not produce any change in the flow pattern; caused prohibitive pressure drops; or, as in the case of the propeller, were mechanically unable to withstand the damaging treatment associated with slug flow. The upstream and downstream flow patterns that were observed during these runs are included as part of the data of Table 3.

In attempting to predict the pressure drops caused by the presence of the turbulators in the test section the correlation presented by Gossage (3) for determining the pressure drops across valves in two-phase flow was employed. Gossage presented a multiplying factor $\psi$, defined as the ratio of the equivalent length of a valve for two-phase flow to the equivalent length of the same valve for single-phase flow, as a function of $X^2$. The use of this correlation requires the values of $X^2$ and the single-phase equivalent length of the valve or turbulator being studied. From this information the equivalent length of the valve or turbulator for two-phase flow can be determined. It was found that this correlation worked satisfactorily in predicting the pressure drops across turbulators for values of $X^2$ greater than about 3, but that for lower values of $X^2$ Gossage's correlation gave values of $\psi$ that were as much as 100 per cent too high. This discrepancy may be due in part to the uncertainty in the values used for the equivalent lengths of some of the turbulators. These equivalent lengths were determined by measuring the pressure drops across the turbulators in single-phase flow, and comparing these values with the pressure drops that would have been expected had there been no turbulator in the line. For several of the turbulators, particularly for the wire gauze and for the 1 1/4-inch orifice, no constant equivalent length was found, but instead the apparent equivalent length increased with increasing flow rates. The curve obtained by plotting the experimental values of $X^2$ and $\psi$ is shown in Fig. 14. The scattering of points on this curve is due not only to experimental error but also to the way in which this error was magnified by the numerical computation of $\psi$. The value of $\psi$ is proportional to the difference of two quantities (see equation 17) which were often of the same order of magnitude. Thus a small percentage error in one of these numbers resulted in a larger percentage error in their difference. Furthermore, this difference was divided by the equivalent length of the turbulator, which was not always accurately known, thus causing a still larger error in the value of $\psi$. In view of these facts the correlation shown in Fig. 14 is probably much better than the distribution of points indicates. For purposes of comparison Gossage's correlation curve is shown in Fig. 15. The results of the calculations of values of $(\frac{\ell}{D})_T$ are included in Table 1. The experimental values of $X^2$ and $\psi$ for the two-phase runs with a turbulator in the line are included along with other pertinent data for these runs in Table 3.

It should be noted that, as in all two-phase flow studies, the uncertainty in some of the results presented is due largely to the difficulty encountered in making accurate pressure drop measurements. The unsteady state conditions which existed in plug and slug flow, in particular, and in all two-phase flow conditions to a lesser degree caused large fluctuations in the pressure drops recorded by the mercury manometer. In many instances the magnitudes of these fluctuations were 100 per cent of the estimated average values of the pressure drop readings.

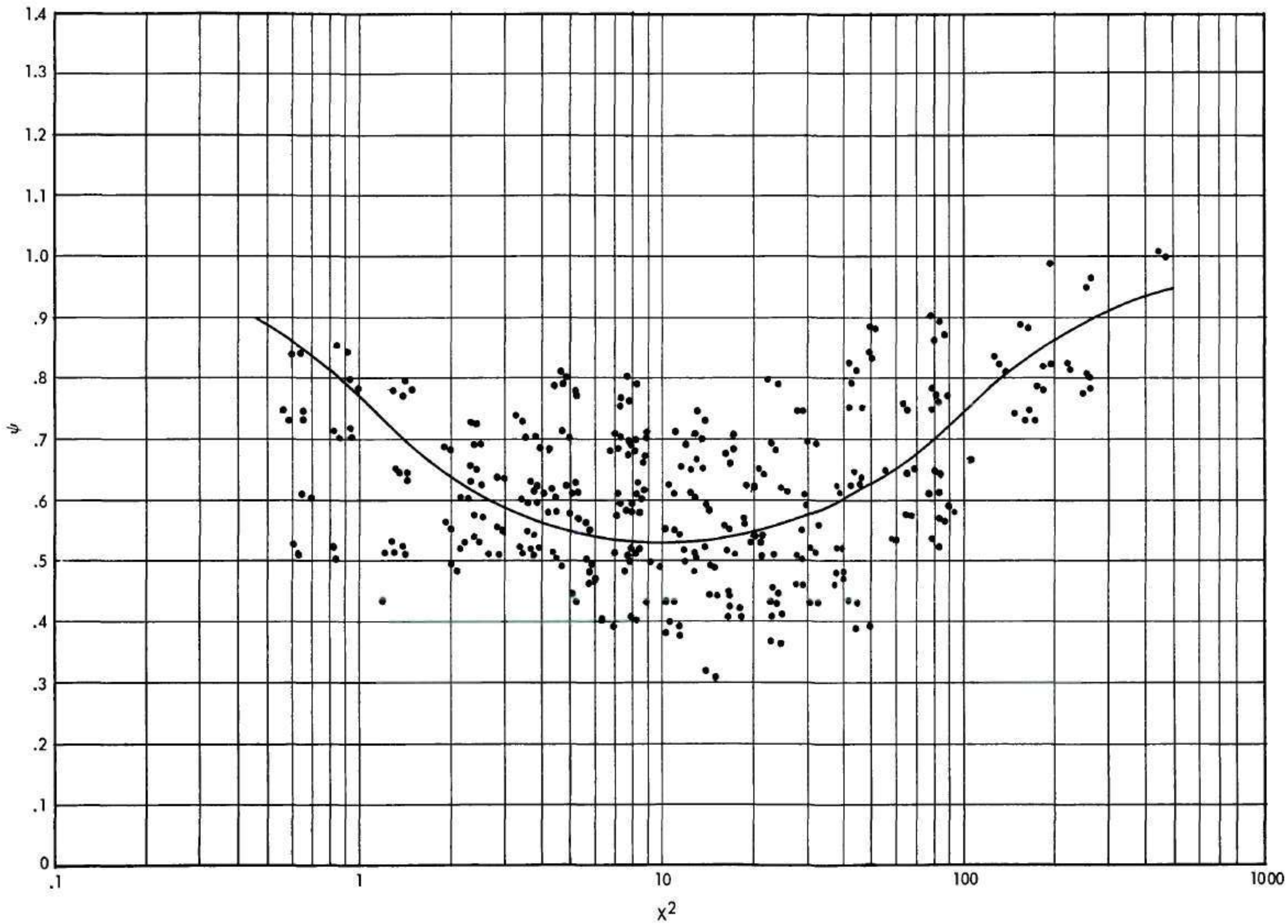



Figure 15. Gossage's Correlation of $\psi$ versus $X^2$.

Table 1A

Data and Results for Flow of Water in 1 1/2 Inch
Pipe Line 314 Inches Long With No Turbulator

| Run Number | $Q_L$ | $\left(\frac{\Delta P}{\Delta \ell}\right)_L \times 10^4$ | $\left(\frac{\ell}{D}\right)_T$ |
|---|---|---|---|
| 1 | 2 | 2.610 | -209.6 |
| 2 | 4 | 8.633 | -209.6 |
| 3 | 6 | 17.497 | -209.6 |
| 4 | 8 | 28.966 | - 74.1 |
| 5 | 10 | 42.889 | - 63.2 |
| 6 | 12 | 59.158 | - 17.3 |
| 7 | 14 | 77.692 | - 17.8 |
| 8 | 20 | 146.274 | - 3.4 |
| 9 | 30 | 317.500 | 4.0 |
| 10 | 40 | 504.169 | 26.8 |
| 11 | 50 | 752.459 | 15.5 |

Table 1B

Data and Results for Flow of Water in 1 1/2 Inch
Pipe Line 314 Inches Long With Wire Gauze Turbulator

| Run Number | $Q_L$ | $\left(\frac{\Delta P}{\Delta \ell}\right)_L \times 10^4$ | $\left(\frac{\ell}{D}\right)_T$ |
|---|---|---|---|
| 70 | 2 | 2.595 | -209.600 |
| 71 | 4 | 8.585 | -209.600 |
| 72 | 6 | 17.405 | - 96.92 |
| 73 | 8 | 28.817 | 130.68 |
| 74 | 10 | 42.673 | 84.54 |
| 75 | 12 | 58.866 | 150.22 |
| 76 | 14 | 77.315 | 186.12 |
| 77 | 20 | 145.587 | 261.89 |
| 78 | 30 | 299.946 | 306.94 |
| 79 | 40 | 501.947 | 384.29 |
| 80 | 50 | 749.181 | 415.01 |

Table 1C

Data and Results for Flow of Water in 1 1/2 Inch
Pipe Line 314 Inches Long With Globe Valve, Full Open, for Turbulator

| Run Number | $Q_L$ | $\left(\frac{\Delta P}{\Delta \ell}\right)_L \times 10^4$ | $\left(\frac{\ell}{D}\right)_T$ |
|---|---|---|---|
| 139 | 4 | 8.531 | -209.600 |
| 140 | 8 | 28.649 | 447.58 |
| 141 | 12 | 58.537 | 339.86 |
| 142 | 20 | 144.810 | 359.22 |
| 143 | 30 | 298.403 | 423.97 |
| 144 | 40 | 499.430 | 446.19 |

Table 1D

Data and Results for Flow of Water in 1 1/2 Inch
Pipe Line 314 Inches Long With Globe Valve, Half Open, for Turbulator

| Run Number | $Q_L$ | $\left(\frac{\Delta P}{\Delta \ell}\right)_L \times 10^4$ | $\left(\frac{\ell}{D}\right)_T$ |
|---|---|---|---|
| 180 | 4 | 8.659 | -119.00 |
| 181 | 8 | 28.966 | 359.14 |
| 182 | 12 | 59.158 | 466.70 |
| 183 | 20 | 146.273 | 554.64 |
| 184 | 30 | 301.308 | 676.92 |
| 185 | 40 | 504.169 | 763.67 |

Table 1E

Data and Results for Flow of Water in 1 1/2 Inch
Pipe Line 314 Inches Long With 3/4 Inch Orifice for Turbulator

| Run Number | $Q_L$ | $\left(\frac{\Delta P}{\Delta \ell}\right)_L \times 10^4$ | $\left(\frac{\ell}{D}\right)_T$ |
|---|---|---|---|
| 220 | 4 | 8.585 | 475.75 |
| 221 | 8 | 28.817 | 947.37 |
| 222 | 12 | 58.866 | 1069.75 |
| 223 | 20 | 145.587 | 1393.45 |
| 224 | 30 | 299.946 | 1553.18 |
| 225 | 40 | 501.947 | 1682.26 |

Table 1F

Data and Results for Flow of Water in 1 1/2 Inch
Pipe Line 314 Inches Long With 1 1/4 Inch Orifice for Turbulator

| Run Number | $Q_L$ | $\left(\frac{\Delta P}{\Delta \ell}\right)_L \times 10^4$ | $\left(\frac{\ell}{D}\right)_T$ |
|---|---|---|---|
| 253 | 2 | 2.610 | -209.60 |
| 254 | 6 | 17.498 | - 97.52 |
| 255 | 10 | 42.889 | 19.04 |
| 256 | 14 | 77.692 | 42.83 |
| 257 | 20 | 145.587 | 67.90 |
| 258 | 30 | 299.946 | 99.02 |
| 259 | 40 | 501.947 | 130.33 |

Table 1G

**Data and Results for Flow of Water in 1 1/2 Inch Pipe Line 314 Inches Long With Two Off Center 1 1/4 Inch Orifices Six Inches Apart for Turbulator**

| Run Number | $Q_L$ | $\left(\frac{\Delta P}{\Delta \ell}\right)_L \times 10^4$ | $\left(\frac{\ell}{D}\right)_T$ |
|---|---|---|---|
| 300 | 2 | 2.577 | -209.60 |
| 301 | 6 | 17.300 | 130.49 |
| 302 | 10 | 42.430 | 252.62 |
| 303 | 14 | 76.888 | 275.04 |
| 304 | 20 | 144.810 | 223.78 |
| 305 | 30 | 298.403 | 205.77 |
| 306 | 40 | 499.430 | 223.93 |

Table 1H

**Data and Results for Flow of Water in 1 1/2 Inch Pipe Line 314 Inches Long With Flat Plate Covering Half of Pipe Diameter for Turbulator**

| Run Number | $Q_L$ | $\left(\frac{\Delta P}{\Delta \ell}\right)_L \times 10^4$ | $\left(\frac{\ell}{D}\right)_T$ |
|---|---|---|---|
| 351 | 2 | 2.595 | -209.60 |
| 352 | 6 | 17.405 | - 96.92 |
| 353 | 10 | 42.673 | 286.76 |
| 354 | 14 | 77.315 | 196.26 |
| 355 | 20 | 145.587 | 194.53 |
| 356 | 30 | 299.946 | 240.25 |
| 357 | 40 | 501.947 | 130.33 |

Table 1I

Data and Results for Flow of Water in 1 1/2 Inch Pipe Line 314 Inches Long With Flat Plate Covering Upper 2/3 Pipe Diameter for Turbulator

| Run Number | $Q_L$ | $\left(\frac{\Delta P}{\Delta \ell}\right)_L \times 10^4$ | $\left(\frac{\ell}{D}\right)_T$ |
|---|---|---|---|
| 400 | 2 | 2.532 | 3664.54 |
| 401 | 6 | 17.028 | 7046.21 |
| 402 | 10 | 41.796 | 4388.90 |
| 403 | 14 | 75.775 | 3558.80 |
| 404 | 20 | 142.781 | 3180.38 |
| 405 | 30 | 294.368 | 3521.34 |

Table 1J

Data and Results for Flow of Water in 1 1/2 Inch Pipe Line 314 Inches Long With Segmented Orifice for Turbulator

| Run Number | $Q_L$ | $\left(\frac{\Delta P}{\Delta \ell}\right)_L \times 10^4$ | $\left(\frac{\ell}{D}\right)_T$ |
|---|---|---|---|
| 435 | 2 | 2.595 | 546.23 |
| 436 | 6 | 17.405 | 849.61 |
| 437 | 10 | 42.673 | 479.78 |
| 438 | 14 | 77.315 | 348.46 |
| 439 | 30 | 299.946 | 232.40 |
| 441 | 40 | 501.947 | 220.19 |

Table 1K

Data and Results for Flow of Water in 1 1/2 Inch
Pipe Line 314 Inches Long With Spiral Coil Turbulator

| Run Number | $Q_L$ | $\left(\frac{\Delta P}{\Delta \ell}\right)_L \times 10^4$ | $\left(\frac{\ell}{D}\right)_T$ |
|---|---|---|---|
| 485 | 2 | 2.577 | 1312.36 |
| 486 | 6 | 17.300 | 470.57 |
| 487 | 10 | 42.430 | 243.38 |
| 488 | 14 | 76.888 | 162.80 |
| 489 | 20 | 144.810 | 120.86 |
| 490 | 30 | 298.403 | 126.90 |
| 491 | 40 | 499.430 | 122.61 |

Table 1L

Data and Results for Flow of Water in 1 1/2 Inch
Pipe Line 314 Inches Long With Propeller for Turbulator

| Run Number | $Q_L$ | $\left(\frac{\Delta P}{\Delta \ell}\right)_L \times 10^4$ | $\left(\frac{\ell}{D}\right)_T$ |
|---|---|---|---|
| 536 | 2 | 2.532 | -209.60 |
| 537 | 6 | 17.029 | 89.85 |
| 538 | 10 | 41.796 | 259.63 |
| 539 | 14 | 75.775 | 214.86 |
| 540 | 20 | 142.781 | 312.36 |
| 541 | 30 | 294.368 | 316.73 |
| 542 | 40 | 492.841 | 339.55 |

Table 1M

Data and Results for Flow of Water in 1 1/2 Inch
Pipe Line 314 Inches Long With Packed Section for Turbulator

| Run Number | $Q_L$ | $\left(\frac{\Delta P}{\Delta \ell}\right)_L \times 10^4$ | $\left(\frac{\ell}{D}\right)_T$ |
|---|---|---|---|
| 566 | 2 | 2.603 | 1297.00 |
| 567 | 6 | 17.456 | 2037.36 |
| 568 | 10 | 42.793 | 2586.01 |
| 569 | 14 | 77.526 | 2598.41 |
| 570 | 20 | 145.971 | 2947.75 |
| 571 | 30 | 300.709 | 3312.24 |

Table 1N

Data and Results for Flow of Water in 1 1/2 Inch
Pipe Line 314 Inches Long With No Turbulator

| Run Number | $Q_L$ | $\left(\frac{\Delta P}{\Delta \ell}\right)_L \times 10^4$ | $\left(\frac{\ell}{D}\right)_T$ |
|---|---|---|---|
| 597 | 2 | 2.602 | 544.11 |
| 598 | 6 | 17.448 | - 29.76 |
| 599 | 10 | 42.774 | -117.90 |
| 600 | 14 | 77.492 | 43.48 |
| 601 | 20 | 145.910 | - 16.05 |
| 602 | 30 | 300.588 | 1.795 |
| 603 | 40 | 502.996 | 7.187 |

Table 2

Data and Results for Co-Current Flow of Air and
Water in 1 1/2 Inch Pipe 314 Inches Long Without Turbulator

| Run No. | $Q_L$ | $W_G$ | $(\frac{\Delta P}{\Delta \ell})_L \times 10^4$ | $(\frac{\Delta P}{\Delta \ell})_G \times 10^4$ | $X^2$ | $\phi^2$ | Flow Pattern |
|---|---|---|---|---|---|---|---|
| 12 | 2 | .01127 | 2.595 | 3.196 | .812 | 0 | st. |
| 13 | 2 | .02127 | 2.595 | 9.731 | .267 | 25.242 | w. |
| 14 | 2 | .03274 | 2.595 | 20.913 | .124 | 60.582 | w. |
| 15 | 2 | .04607 | 2.595 | 38.614 | .067 | 101.690 | w. |
| 16 | 2 | .06286 | 2.595 | 67.907 | .038 | 157.224 | w. |
| 17 | 4 | .01206 | 8.486 | 3.718 | 2.282 | 43.662 | p. |
| 18 | 4 | .02181 | 8.486 | 10.484 | .809 | 48.072 | p. |
| 19 | 4 | .03274 | 8.486 | 21.398 | .397 | 48.072 | p. |
| 20 | 4 | .04693 | 8.486 | 40.564 | .209 | 52.483 | p. |
| 21 | 4 | .06476 | 8.486 | 67.532 | .126 | 61.524 | p. |
| 22 | 4 | .08353 | 8.486 | 100.564 | .084 | 74.976 | p. |
| 23 | 6 | .01177 | 17.122 | 3.562 | 4.807 | 23.827 | p. |
| 24 | 6 | .02185 | 17.122 | 10.583 | 1.618 | 30.495 | p. |
| 25 | 6 | .03420 | 17.122 | 21.721 | .788 | 30.495 | s. |
| 26 | 6 | .04876 | 17.122 | 40.784 | .420 | 34.867 | s. |
| 27 | 6 | .06579 | 17.122 | 66.069 | .259 | 43.501 | s. |
| 28 | 6 | .08560 | 17.122 | 99.819 | .172 | 47.545 | s. |
| 29 | 8 | .01209 | 28.362 | 3.513 | 8.074 | 18.409 | p. |
| 30 | 8 | .02289 | 28.362 | 10.126 | 2.801 | 22.302 | p. |
| 31 | 8 | .03492 | 28.362 | 21.392 | 1.326 | 24.743 | s. |
| 32 | 8 | .04871 | 28.362 | 36.359 | .780 | 26.261 | s. |
| 33 | 8 | .06766 | 28.362 | 66.099 | .429 | 32.596 | s. |
| 34 | 8 | .09188 | 28.362 | 108.700 | .261 | 37.742 | s. |
| 35 | 10 | .01239 | 41.796 | 3.459 | 12.084 | 14.238 | p. |
| 36 | 10 | .02339 | 41.796 | 10.579 | 3.951 | 16.835 | s. |
| 37 | 10 | .03559 | 41.796 | 21.049 | 1.986 | 20.327 | s. |
| 38 | 10 | .05032 | 41.796 | 37.028 | 1.129 | 23.775 | s. |
| 39 | 10 | .06944 | 41.796 | 63.027 | .663 | 29.103 | s. |
| 40 | 10 | .09282 | 41.796 | 100.989 | .414 | 31.790 | s. |
| 41 | 12 | .01240 | 57.677 | 3.510 | 16.433 | 13.465 | p. |
| 42 | 12 | .02341 | 57.677 | 10.120 | 5.699 | 16.061 | s. |
| 43 | 12 | .03693 | 57.677 | 22.824 | 2.527 | 18.559 | s. |
| 44 | 12 | .05193 | 57.677 | 37.651 | 1.532 | 21.739 | s. |
| 45 | 12 | .06772 | 57.677 | 57.466 | 1.004 | 23.036 | s. |
| 46 | 12 | .09290 | 57.677 | 97.282 | .593 | 26.800 | s. |
| 47 | 14 | .01276 | 75.389 | 3.666 | 20.562 | 11.245 | p. |
| 48 | 14 | .02402 | 75.389 | 10.486 | 7.190 | 12.660 | s. |
| 49 | 14 | .03711 | 75.389 | 21.621 | 3.487 | 15.639 | s. |

Table 2 (Continued)

Data and Results for Co-Current Flow of Air and Water in 1 1/2 Inch Pipe 314 Inches Long Without Turbulator

| Run No. | $Q_L$ | $W_G$ | $(\frac{\Delta P}{\Delta \ell})_L \times 10^4$ | $(\frac{\Delta P}{\Delta \ell})_G \times 10^4$ | $X^2$ | $\phi^2$ | Flow Pattern |
|---|---|---|---|---|---|---|---|
| 50 | 14 | .05296 | 75.389 | 38.849 | 1.941 | 18.120 | s. |
| 51 | 14 | .07071 | 75.389 | 62.140 | 1.213 | 20.057 | s. |
| 52 | 14 | .09522 | 75.389 | 101.725 | .741 | 22.887 | s. |
| 53 | 20 | .01333 | 142.076 | 3.762 | 37.762 | 6.981 | p. |
| 54 | 20 | .02497 | 142.076 | 10.199 | 13.930 | 8.562 | s. |
| 55 | 20 | .03961 | 142.076 | 22.287 | 6.375 | 10.880 | s. |
| 56 | 20 | .05592 | 142.076 | 37.683 | 3.770 | 12.671 | s. |
| 57 | 20 | .07655 | 142.076 | 63.478 | 2.238 | 13.936 | s. |
| 58 | 20 | .09883 | 142.076 | 88.736 | 1.601 | 15.476 | s. |
| 59 | 30 | .01437 | 294.368 | 3.755 | 78.403 | 4.768 | s. |
| 60 | 30 | .02755 | 294.368 | 10.793 | 27.274 | 5.741 | s. |
| 61 | 30 | .04300 | 294.368 | 22.307 | 13.197 | 6.484 | s. |
| 62 | 30 | .06123 | 294.368 | 36.832 | 7.992 | 7.946 | s. |
| 63 | 30 | .08245 | 294.368 | 56.745 | 5.188 | 9.186 | s. |
| 64 | 40 | .01608 | 492.841 | 3.881 | 126.973 | 3.873 | s. |
| 65 | 40 | .03732 | 492.841 | 10.839 | 45.468 | 4.602 | s. |
| 66 | 40 | .04616 | 492.841 | 21.253 | 23.189 | 5.935 | s. |
| 67 | 40 | .06627 | 492.841 | 36.616 | 13.460 | 6.474 | s. |
| 68 | 40 | .08886 | 492.841 | 54.898 | 8.977 | 7.150 | s. |
| 69 | 40 | .11254 | 492.841 | 75.478 | 6.530 | 7.906 | s. |
| 604 | 2 | .01147 | 2.586 | 3.304 | .783 | 45.590 | w. |
| 605 | 2 | .02135 | 2.586 | 9.820 | .263 | 73.812 | w. |
| 606 | 2 | .03211 | 2.586 | 20.318 | .127 | 115.784 | w. |
| 607 | 2 | .04622 | 2.586 | 38.928 | .066 | 144.730 | w. |
| 608 | 2 | .06403 | 2.586 | 124.657 | .021 | 170.782 | w. |
| 609 | 2 | .08711 | 2.586 | 113.249 | .023 | 186.702 | w.-a. |
| 610 | 2 | .11366 | 2.586 | 172.879 | .015 | 242.423 | w.-a. |
| 611 | 6 | .01211 | 17.258 | 3.473 | 4.970 | 23.313 | p. |
| 612 | 6 | .02242 | 17.258 | 9.690 | 1.781 | 34.160 | p. |
| 613 | 6 | .03429 | 17.258 | 19.351 | .892 | 38.494 | p. |
| 614 | 6 | .04796 | 17.258 | 35.019 | .493 | 38.494 | p. |
| 615 | 6 | .06687 | 17.258 | 59.961 | .287 | 42.432 | w.-a. |
| 616 | 6 | .08916 | 17.258 | 101.179 | .171 | 51.181 | w.-a. |
| 617 | 6 | .10613 | 17.258 | 131.359 | .131 | 55.302 | w.-a. |
| 618 | 10 | .01241 | 42.118 | 3.685 | 11.430 | 13.996 | p. |
| 619 | 10 | .02293 | 42.118 | 10.205 | 4.127 | 17.506 | p. |
| 620 | 10 | .03564 | 42.118 | 20.970 | 2.008 | 19.328 | p. |
| 621 | 10 | .05040 | 42.118 | 36.999 | 1.138 | 23.638 | p. |

Table 2 (Concluded)

Data and Results for Co-Current Flow of Air and
Water in 1 1/2 Inch Pipe 314 Inches Long Without Turbulator

| Run No. | $Q_L$ | $W_G$ | $(\frac{\Delta P}{\Delta \ell})_L \times 10^4$ | $(\frac{\Delta P}{\Delta \ell})_G \times 10^4$ | $X^2$ | $\phi^2$ | Flow Pattern |
|---|---|---|---|---|---|---|---|
| 622 | 10 | .06867 | 42.118 | 58.038 | .726 | 27.103 | s.-a. |
| 623 | 10 | .09204 | 42.118 | 90.053 | .468 | 33.323 | s.-a. |
| 624 | 10 | .10133 | 42.118 | 107.385 | .392 | 34.879 | s.-a. |
| 625 | 14 | .01271 | 76.157 | 3.643 | 20.904 | 9.731 | p. |
| 626 | 14 | .02440 | 76.157 | 10.948 | 6.956 | 13.515 | s. |
| 627 | 14 | .03696 | 76.157 | 21.609 | 3.524 | 14.989 | s. |
| 629 | 14 | .07042 | 76.157 | 58.954 | 1.292 | 19.314 | s. |
| 630 | 14 | .09298 | 76.157 | 93.158 | 8.175 | 21.698 | s.-a. |
| 631 | 20 | .01326 | 143.478 | 3.558 | 40.325 | 6.926 | p. |
| 632 | 20 | .02485 | 143.478 | 10.175 | 14.101 | 7.956 | s. |
| 633 | 20 | .03881 | 143.478 | 21.255 | 6.750 | 8.478 | s. |
| 634 | 20 | .05419 | 143.478 | 37.447 | 3.831 | 11.269 | s.-a. |
| 635 | 20 | .07374 | 143.478 | 59.530 | 2.410 | 12.782 | s.-a. |
| 636 | 20 | .09656 | 143.478 | 85.430 | 1.679 | 14.321 | s.-a. |
| 637 | 30 | .01434 | 293.687 | 3.710 | 79.155 | 4.142 | s. |
| 638 | 30 | .02750 | 293.687 | 10.680 | 27.500 | 5.136 | s. |
| 639 | 30 | .04233 | 293.687 | 21.230 | 13.833 | 6.251 | s. |
| 640 | 30 | .05928 | 293.687 | 35.189 | 8.346 | 7.474 | s.-a. |
| 641 | 30 | .08007 | 293.687 | 55.333 | 5.308 | 8.233 | s.-a. |
| 642 | 30 | .10434 | 293.687 | 83.652 | 3.511 | 9.201 | s.-a. |
| 643 | 40 | .01579 | 491.728 | 3.736 | 131.619 | 3.368 | s. |
| 644 | 40 | .02987 | 491.728 | 10.638 | 46.223 | 3.958 | s. |
| 645 | 40 | .04549 | 491.728 | 20.831 | 23.605 | 4.319 | s.-a. |
| 646 | 40 | .06544 | 491.728 | 35.652 | 13.792 | 5.952 | s.-a. |
| 647 | 40 | .08719 | 491.728 | 52.670 | 9.336 | 6.405 | s.-a. |

Table 3A

Data and Results for Co-Current Flow of Air and Water
in 1 1/2 Inch Pipe 314 Inches Long With Wire Gauze for Turbulator

| Run No. | $Q_L$ | $W_G$ | $(\frac{\Delta P}{\Delta \ell})_L \times 10^4$ | $(\frac{\Delta P}{\Delta \ell})_G \times 10^4$ | $X^2$ | $\phi^2$ | $(\frac{\Delta P}{\Delta \ell})_{T-P} \times 10^3$ | $\psi$ | Flow Pattern Upstream | Flow Pattern Downstream |
|---|---|---|---|---|---|---|---|---|---|---|
| 81 | 2 | .01182 | 2.619 | 3.479 | .753 | 18.876 | 4.944 | 1.769 | s. | s. |
| 82 | 2 | .02141 | 2.619 | 9.966 | .263 | 30.119 | 7.888 | 2.378 | w. | w. |
| 83 | 2 | .03367 | 2.619 | 22.261 | .118 | 43.034 | 11.271 | 2.001 | w. | w. |
| 84 | 2 | .04808 | 2.619 | 41.987 | .062 | 57.038 | 14.938 | 1.577 | w. | w. |
| 85 | 2 | .06230 | 2.516 | 62.665 | .040 | 69.362 | 17.451 | 1.653 | w. | w. |
| 86 | 2 | .08839 | 2.516 | 110.832 | .023 | 89.346 | 22.479 | 1.559 | p. | p. |
| 87 | 4 | .01182 | 8.585 | 3.550 | 2.418 | 11.243 | 9.652 | 2.049 | p. | p. |
| 88 | 4 | .02195 | 8.585 | 10.511 | .817 | 18.205 | 15.628 | 1.319 | p. | p. |
| 89 | 4 | .03367 | 8.585 | 22.318 | .384 | 25.462 | 21.859 | .887 | p. | p. |
| 90 | 4 | .04891 | 8.585 | 40.785 | .210 | 33.238 | 28.534 | .764 | s.-a. | s.-a. |
| 91 | 4 | .06612 | 8.585 | 65.738 | .131 | 41.085 | 35.271 | .656 | s. | s.-a. |
| 92 | 4 | .08938 | 8.585 | 114.420 | .075 | 52.547 | 45.111 | .661 | s.-a. | s.a. |
| 93 | 6 | .01214 | 17.405 | 3.526 | 4.936 | 8.190 | 14.255 | 2.016 | p. | p. |
| 94 | 6 | .02195 | 17.405 | 9.974 | 1.745 | 12.995 | 22.618 | 1.236 | s. | s.-a. |
| 95 | 6 | .03437 | 17.405 | 21.797 | .798 | 18.389 | 32.005 | .546 | s. | s. |
| 96 | 6 | .04973 | 17.405 | 40.078 | .434 | 23.098 | 41.943 | .649 | s. | s.-a. |
| 97 | 6 | .06974 | 17.405 | 70.205 | .248 | 30.909 | 53.796 | .454 | s.-a. | s.-a. |
| 98 | 6 | .08937 | 17.405 | 108.776 | .160 | 37.542 | 65.341 | .405 | s.-a. | s.a. |
| 99 | 8 | .01244 | 28.656 | 3.716 | 7.712 | 6.718 | 19.252 | 1.680 | p. | w.-a. |
| 100 | 8 | .02248 | 28.649 | 9.797 | 2.924 | 10.333 | 29.604 | .951 | s. | s.-a. |
| 101 | 8 | .03574 | 28.649 | 21.651 | 1.323 | 14.694 | 42.097 | .644 | s. | s.-a. |
| 102 | 8 | .05053 | 28.649 | 36.744 | .780 | 18.584 | 53.242 | .463 | s.-a. | s.-a. |
| 103 | 8 | .06972 | 28.649 | 63.235 | .453 | 23.649 | 67.753 | .575 | s.-a. | s.a. |
| 104 | 8 | .09226 | 28.649 | 105.310 | .272 | 29.660 | 84.974 | .439 | s.-a. | a. |
| 105 | 10 | .01244 | 42.228 | 3.728 | 11.327 | 5.664 | 23.918 | 1.328 | s. | s. |
| 106 | 10 | .02398 | 42.228 | 10.499 | 4.022 | 8.969 | 37.877 | .971 | s. | s. |

Table 3A (Continued)

Data and Results for Co-Current Flow of Air and Water
in 1 1/2 Inch Pipe 314 Inches Long With Wire Gauze for Turbulator

| Run No. | $Q_L$ | $W_G$ | $(\frac{\Delta P}{\Delta \ell})_L \times 10^4$ | $(\frac{\Delta P}{\Delta \ell})_G \times 10^4$ | $X^2$ | $\phi^2$ | $(\frac{\Delta P}{\Delta \ell})_{T-P} \times 10^3$ | $\psi$ | Flow Pattern Upstream | Flow Pattern Downstream |
|---|---|---|---|---|---|---|---|---|---|---|
| 107 | 10 | .03640 | 42.228 | 20.915 | 2.019 | 12.181 | 51.536 | .774 | s. | s.-a. |
| 108 | 10 | .05210 | 42.228 | 39.671 | 1.064 | 16.185 | 68.345 | .495 | s. | s.-a. |
| 109 | 10 | .06972 | 42.228 | 60.203 | .701 | 19.478 | 82.250 | .417 | s. | s.-a. |
| 110 | 10 | .09321 | 42.228 | 97.807 | .432 | 24.161 | 102.026 | .394 | s.-a. | a. |
| 111 | 12 | .01274 | 58.114 | 3.459 | 16.799 | 4.755 | 27.631 | 1.400 | s. | s. |
| 112 | 12 | .02399 | 58.114 | 10.527 | 5.520 | 7.793 | 45.290 | .756 | s. | s.-a. |
| 113 | 12 | .03705 | 58.114 | 21.704 | 2.678 | 10.746 | 62.447 | .602 | s. | s.-a. |
| 114 | 12 | .05287 | 58.114 | 39.099 | 1.486 | 13.955 | 81.099 | .493 | s. | a. |
| 115 | 12 | .07146 | 58.114 | 60.891 | .954 | 16.988 | 98.727 | .426 | s. | a. |
| 116 | 12 | .09414 | 58.114 | 92.259 | .630 | 20.430 | 118.730 | .434 | s. | a. |
| 117 | 14 | .01303 | 76.157 | 3.639 | 20.929 | 4.313 | 328.436 | 1.355 | s. | s.-a. |
| 118 | 14 | .02446 | 76.157 | 10.421 | 7.308 | 6.881 | 524.000 | .794 | s. | s.-a. |
| 119 | 14 | .03769 | 76.157 | 20.079 | 3.793 | 9.207 | 70.115 | .501 | s. | s.-a. |
| 120 | 14 | .05362 | 76.157 | 36.653 | 2.078 | 12.026 | 91.950 | .537 | s. | a. |
| 121 | 14 | .07315 | 75.157 | 61.256 | 1.243 | 15.017 | 115.048 | .398 | s. | a. |
| 122 | 14 | .09598 | 76.157 | 92.274 | .825 | 18.120 | 138.000 | .377 | s.-a. | a. |
| 123 | 20 | .01358 | 142.781 | 3.820 | 37.376 | 3.333 | 47.599 | 1.333 | s. | s.-a. |
| 124 | 20 | .02583 | 142.781 | 10.582 | 13.493 | 5.241 | 74.826 | .712 | s. | s.-a. |
| 125 | 20 | .04012 | 142.781 | 22.123 | 6.454 | 7.271 | 103.816 | .464 | s. | a. |
| 126 | 20 | .05650 | 142.781 | 37.454 | 3.803 | 9.196 | 131.297 | .395 | s. | a. |
| 127 | 20 | .07636 | 142.781 | 57.579 | 2.480 | 11.118 | 158.748 | .404 | s. | a. |
| 128 | 20 | .09947 | 142.781 | 86.811 | 1.645 | 13.342 | 190.492 | .365 | s. | a. |
| 129 | 30 | .01512 | 294.368 | 3.687 | 79.832 | 2.380 | 70.061 | 1.231 | s. | a. |
| 130 | 30 | .02878 | 294.368 | 10.665 | 27.601 | 3.814 | 112.272 | .792 | s. | a. |
| 131 | 30 | .04405 | 294.368 | 21.075 | 13.968 | 5.161 | 151.918 | .542 | s. | a. |
| 132 | 30 | .06253 | 294.368 | 35.768 | 8.230 | 6.527 | 192.135 | .467 | s.-a. | a. |

Table 3A (Concluded)

Data and Results for Co-Current Flow of Air and Water
in 1 1/2 Inch Pipe 314 Inches Long with Wire Gauze for Turbulator

| Run No. | $Q_L$ | $W_G$ | $(\frac{\Delta P}{\Delta \ell})_L \times 10^4$ | $(\frac{\Delta P}{\Delta \ell})_G \times 10^4$ | $X^2$ | $\phi^2$ | $(\frac{\Delta P}{\Delta \ell})_{T\text{-}P} \times 10^3$ | $\psi$ | Flow Pattern Upstream | Flow Pattern Downstream |
|---|---|---|---|---|---|---|---|---|---|---|
| 133 | 30 | .08392 | 294.368 | 53.218 | 5.531 | 7.863 | 229.207 | .384 | s.-a. | a. |
| 134 | 30 | .09663 | 294.368 | 64.852 | 4.539 | 8.501 | 250.237 | .363 | s.-a. | a. |
| 135 | 40 | .01654 | 491.665 | 3.815 | 128.887 | 1.924 | 94.600 | 1.405 | s. | a. |
| 136 | 40 | .03184 | 491.665 | 10.954 | 46.409 | 3.028 | 148.884 | .916 | s. | a. |
| 137 | 40 | .04965 | 491.665 | 20.652 | 23.807 | 4.073 | 200.248 | .677 | s.-a. | a. |
| 138 | 40 | .06806 | 491.665 | 32.250 | 15.245 | 4.964 | 244.067 | .506 | s.-a. | a. |

Table 3B

Data and Results for Co-Current Flow of Air and Water
in 1 1/2 Inch Pipe 314 Inches Long With Globe Valve, Full Open, for Turbulator

| Run No. | $Q_L$ | $W_G$ | $(\frac{\Delta P}{\Delta \ell})_L \times 10^4$ | $(\frac{\Delta P}{\Delta \ell})_G \times 10^4$ | $X^2$ | $\phi^2$ | $(\frac{\Delta P}{\Delta \ell})_{T-P} \times 10^3$ | $\psi$ | Flow Pattern Upstream | Flow Pattern Downstream |
|---|---|---|---|---|---|---|---|---|---|---|
| 145 | 4 | .01208 | 8.531 | 3.664 | 2.328 | 11.434 | 9.754 | .700 | p. | p. |
| 146 | 4 | .02185 | 8.531 | 10.439 | .817 | 18.200 | 15.526 | .758 | p. | w.-a. |
| 147 | 4 | .03350 | 8.531 | 22.443 | .380 | 25.562 | 21.807 | .744 | p. | w.-a. |
| 148 | 4 | .04867 | 8.487 | 40.771 | .208 | 33.402 | 28.349 | .587 | s. | a. |
| 149 | 4 | .06486 | 8.486 | 68.534 | .123 | 42.067 | 35.700 | .519 | s. | a. |
| 150 | 4 | .08796 | 8.486 | 112.139 | .076 | 52.347 | 44.424 | .533 | s. | a. |
| 151 | 4 | .10587 | 8.486 | 147.576 | .058 | 59.135 | 50.184 | .488 | s.-a. | a. |
| 152 | 8 | .01209 | 28.510 | 3.565 | 7.996 | 6.111 | 18.848 | 1.447 | p. | w.-a. |
| 153 | 8 | .02341 | 28.510 | 10.606 | 2.688 | 10.727 | 30.582 | .762 | s. | w.-a. |
| 154 | 8 | .03494 | 28.510 | 20.402 | 1.397 | 14.343 | 40.891 | .626 | s. | a. |
| 155 | 8 | .04956 | 28.510 | 36.074 | .790 | 18.473 | 52.665 | .513 | s. | a. |
| 156 | 8 | .06861 | 28.510 | 61.758 | .462 | 23.453 | 66.865 | .470 | s. | a. |
| 157 | 8 | .09383 | 28.510 | 103.569 | .275 | 29.505 | 84.118 | .383 | s.-a. | a. |
| 158 | 12 | .01271 | 57.993 | 3.710 | 15.630 | 4.909 | 28.471 | 1.271 | s. | w.-a. |
| 159 | 12 | .02392 | 57.972 | 10.669 | 5.433 | 7.848 | 45.499 | .811 | s. | a. |
| 160 | 12 | .03696 | 57.972 | 21.795 | 2.660 | 10.777 | 62.479 | .541 | s. | a. |
| 161 | 12 | .05197 | 57.972 | 35.840 | 1.618 | 13.441 | 77.918 | .379 | s. | a. |
| 162 | 12 | .07128 | 57.972 | 58.062 | .999 | 16.647 | 96.505 | .386 | s. | a. |
| 163 | 12 | .09572 | 57.972 | 95.753 | .605 | 20.793 | 120.540 | .364 | s.-a. | a. |
| 164 | 20 | .01422 | 142.781 | 3.559 | 40.119 | 3.230 | 46.125 | 1.181 | s. | a. |
| 165 | 20 | .02589 | 142.781 | 10.728 | 13.309 | 5.273 | 75.284 | .748 | s. | a. |
| 166 | 20 | .04022 | 142.781 | 21.262 | 6.715 | 7.144 | 102.001 | .507 | s. | a. |
| 167 | 20 | .05735 | 142.781 | 37.231 | 3.835 | 9.161 | 130.807 | .457 | s.-a. | a. |
| 168 | 20 | .07814 | 142.781 | 61.033 | 2.339 | 11.410 | 162.907 | .452 | s.-a. | a. |
| 169 | 20 | .10059 | 142.781 | 85.131 | 1.677 | 13.226 | 188.847 | .348 | s.-a. | a. |
| 170 | 30 | .01493 | 292.964 | 3.615 | 81.039 | 2.364 | 69.264 | 1.198 | s. | a. |

Table 3B (Concluded)

Data and Results for Co-Current Flow of Air and Water
in 1 1/2 Inch Pipe 314 Inches Long With Globe Valve, Full Open, for Turbulator

| Run No. | $Q_L$ | $W_G$ | $(\frac{\Delta P}{\Delta \ell})_L \times 10^4$ | $(\frac{\Delta P}{\Delta \ell})_G \times 10^4$ | $X^2$ | $\phi^2$ | $(\frac{\Delta P}{\Delta \ell})_{T\text{-}P} \times 10^3$ | $\psi$ | Flow Pattern Upstream | Flow Pattern Downstream |
|---|---|---|---|---|---|---|---|---|---|---|
| 171 | 30 | .02888 | 292.964 | 10.359 | 28.280 | 3.773 | 110.538 | .832 | s. | a. |
| 172 | 30 | .04527 | 292.964 | 21.009 | 13.945 | 5.165 | 151.303 | .714 | s. | a. |
| 173 | 30 | .06337 | 292.964 | 34.386 | 8.520 | 6.427 | 188.301 | .522 | s.-a. | a. |
| 174 | 30 | .08492 | 292.964 | 54.468 | 5.379 | 7.884 | 230.966 | .369 | s.-a. | a. |
| 175 | 30 | .10815 | 292.964 | 77.226 | 3.794 | 9.206 | 269.692 | .306 | s.-a. | a. |
| 176 | 40 | .01704 | 490.546 | 3.763 | 130.355 | 1.914 | 93.911 | 1.459 | s. | a. |
| 177 | 40 | .03231 | 490.546 | 10.474 | 46.836 | 3.016 | 147.944 | .838 | s. | a. |
| 178 | 40 | .04981 | 490.546 | 20.073 | 24.438 | 4.025 | 197.484 | .626 | s. | a. |
| 179 | 40 | .07004 | 490.546 | 32.507 | 15.091 | 4.987 | 244.618 | .566 | s. | a. |

Table 3C

Data and Results for Co-Current Flow of Air and Water in 1 1/2 Inch Pipe 314 Inches Long With Globe Valve, Half Open, for Turbulator

| Run No. | $Q_L$ | $W_G$ | $(\frac{\Delta P}{\Delta \ell})_L \times 10^4$ | $(\frac{\Delta P}{\Delta \ell})_G \times 10^4$ | $X^2$ | $\phi^2$ | $(\frac{\Delta P}{\Delta \ell})_{T-P} \times 10^3$ | $\psi$ | Flow Pattern Upstream | Flow Pattern Downstream |
|---|---|---|---|---|---|---|---|---|---|---|
| 186 | 4 | .01179 | 8.585 | 3.498 | 2.454 | 11.170 | 9.589 | .433 | p. | w.-a. |
| 187 | 4 | .02188 | 8.585 | 10.393 | .826 | 18.113 | 15.550 | .377 | p. | w.-a. |
| 188 | 4 | .03356 | 8.585 | 20.852 | .411 | 24.676 | 21.184 | .412 | p. | w.-a. |
| 189 | 4 | .04792 | 8.585 | 20.029 | .214 | 32.963 | 28.298 | .520 | p. | w.-a. |
| 190 | 4 | .06497 | 8.585 | 64.756 | .133 | 40 809 | 35.034 | .428 | p. | a. |
| 191 | 4 | .08810 | 8.585 | 106.165 | .081 | 50.829 | 43.636 | .410 | s.-a. | a. |
| 192 | 4 | .10808 | 8.585 | 147.486 | .058 | 58.817 | 50.493 | .502 | s.-a. | a. |
| 193 | 8 | .01211 | 28.817 | 3.590 | 8.027 | 6.600 | 19.019 | .997 | p. | w.-a. |
| 194 | 8 | .02293 | 28.817 | 9.712 | 2.967 | 10.267 | 29.586 | .646 | s. | a. |
| 195 | 8 | .03565 | 28.817 | 20.055 | 1.437 | 14.166 | 40.823 | .464 | s. | a. |
| 196 | 8 | .05041 | 28.817 | 37.417 | .766 | 18.734 | 53.672 | .363 | s. | a. |
| 197 | 8 | .06867 | 28.817 | 61.903 | .463 | 23.425 | 67.126 | .298 | s. | a. |
| 198 | 8 | .09203 | 28.817 | 101.897 | .281 | 29.229 | 83.739 | .341 | s.-a. | a. |
| 199 | 12 | .01297 | 58.397 | 3.671 | 15.908 | 4.871 | 28.446 | .929 | s. | a. |
| 200 | 12 | .02388 | 58.397 | 10.148 | 5.754 | 7.651 | 44.679 | .582 | s. | a. |
| 201 | 12 | .03754 | 58.397 | 21.584 | 2.706 | 10.696 | 62.462 | .437 | s. | a. |
| 202 | 12 | .05340 | 58.397 | 36.828 | 1.582 | 13.574 | 79.085 | .381 | s. | a. |
| 203 | 12 | .07201 | 58.397 | 60.438 | .964 | 16.913 | 98.540 | .314 | s.-a. | a. |
| 204 | 12 | .09558 | 58.397 | 96.959 | .601 | 20.862 | 121.550 | .262 | s.-a. | a. |
| 205 | 20 | .01407 | 144.166 | 3.755 | 38.395 | 3.294 | 47.489 | .923 | s. | a. |
| 206 | 20 | .02663 | 144.166 | 10.545 | 13.672 | 5.210 | 75.112 | .605 | s. | a. |
| 207 | 20 | .04057 | 144.166 | 21.384 | 6.742 | 7.131 | 102.812 | .424 | s. | a. |
| 208 | 20 | .05909 | 144.166 | 37.698 | 3.824 | 9.173 | 132.241 | .417 | s.-a. | a. |
| 209 | 20 | .07847 | 144.166 | 56.256 | 2.563 | 10.957 | 157.964 | .375 | s.-a. | a. |
| 210 | 20 | .09818 | 144.166 | 79.161 | 1.821 | 12.751 | 183.832 | .341 | s.-a. | a. |
| 211 | 30 | .01557 | 295.755 | 3.757 | 78.719 | 2.395 | 70.832 | 1.028 | s. | a. |

Table 3C (Concluded)

Data and Results for Co-Current Flow of Air and Water
in 1 1/2 Inch Pipe 314 Inches Long With Globe Valve, Half Open, for Turbulator

| Run No. | $Q_L$ | $W_G$ | $(\frac{\Delta P}{\Delta \ell})_L \times 10^4$ | $(\frac{\Delta P}{\Delta \ell})_G \times 10^4$ | $X^2$ | $\phi^2$ | $(\frac{\Delta P}{\Delta \ell})_{T-P} \times 10^3$ | $\psi$ | Flow Pattern Upstream | Flow Pattern Downstream |
|---|---|---|---|---|---|---|---|---|---|---|
| 212 | 30 | .02989 | 295.755 | 10.706 | 27.625 | 3.813 | 112.757 | .706 | s. | a. |
| 213 | 30 | .04605 | 295.755 | 20.979 | 14.097 | 5.139 | 152.008 | .561 | s.-a. | a. |
| 214 | 30 | .06550 | 295.755 | 35.887 | 8.241 | 6.523 | 192.924 | .447 | s.-a. | a. |
| 215 | 30 | .08514 | 295.755 | 53.804 | 5.497 | 7.808 | 230.926 | .337 | s.-a. | a. |
| 216 | 30 | .10700 | 295.755 | 68.404 | 4.324 | 8.687 | 256.902 | .312 | s.-a. | a. |
| 217 | 40 | .01736 | 492.841 | 3.669 | 134.333 | 1.889 | 93.099 | 1.172 | s. | a. |
| 218 | 40 | .03316 | 492.841 | 9.814 | 50.215 | 2.924 | 144.109 | .742 | s.-a. | a. |
| 219 | 40 | .04948 | 492.841 | 18.912 | 26.060 | 3.913 | 192.828 | .516 | s.-a. | a. |

Table 3D

Data and Results for Co-Current Flow of Air and Water
in 1 1/2 Inch Pipe 314 Inches Long With 3/4 Inch Orifice for Turbulator

| Run No. | $Q_L$ | $W_G$ | $(\frac{\Delta P}{\Delta \ell})_L \times 10^4$ | $(\frac{\Delta P}{\Delta \ell})_G \times 10^4$ | $X^2$ | $\phi^2$ | $(\frac{\Delta P}{\Delta \ell})_{T-P} \times 10^3$ | $\psi$ | Flow Pattern Upstream | Flow Pattern Downstream |
|---|---|---|---|---|---|---|---|---|---|---|
| 226 | 4 | .01210 | 8.531 | 3.455 | 2.469 | 11.140 | 9.504 | .381 | p. | w.-a. |
| 227 | 4 | .02240 | 8.486 | 10.320 | .822 | 18.150 | 15.403 | .396 | p. | a. |
| 228 | 4 | .03356 | 8.486 | 21.346 | .398 | 25.062 | 21.268 | .377 | s. | a. |
| 229 | 4 | .04792 | 8.486 | 37.957 | .224 | 32.360 | 27.462 | .335 | s. | a. |
| 230 | 4 | .06590 | 8.486 | 64.267 | .132 | 40.884 | 34.695 | .360 | s. | a. |
| 231 | 4 | .09020 | 8.486 | 108.467 | .078 | 51.579 | 43.772 | .378 | s.-a. | a. |
| 232 | 8 | .01242 | 28.434 | 3.549 | 8.012 | 6.605 | 18.782 | .586 | s. | a. |
| 233 | 8 | .02394 | 28.434 | 11.224 | 2.533 | 11.013 | 31.315 | .325 | s. | a. |
| 234 | 8 | .03634 | 28.434 | 21.355 | 1.331 | 14.653 | 41.666 | .353 | s. | a. |
| 235 | 8 | .05045 | 28.434 | 36.497 | .779 | 18.591 | 52.861 | .298 | s. | a. |
| 236 | 8 | .07048 | 28.434 | 60.694 | .468 | 23.301 | 66.253 | .282 | s.-a. | a. |
| 237 | 8 | .09305 | 28.434 | 93.115 | .305 | 28.177 | 80.119 | .301 | s.-a. | a. |
| 238 | 12 | .01297 | 58.866 | 3.508 | 16.780 | 4.757 | 28.003 | .540 | s. | a. |
| 239 | 12 | .02483 | 58.866 | 9.898 | 5.947 | 7.540 | 44.385 | .359 | s. | a. |
| 240 | 12 | .03816 | 58.866 | 20.327 | 2.896 | 10.378 | 61.091 | .274 | s. | a. |
| 241 | 12 | .05340 | 58.866 | 36.033 | 1.634 | 13.382 | 78.773 | .261 | s. | a. |
| 242 | 12 | .07285 | 58.866 | 57.723 | 1.020 | 16.496 | 97.104 | .222 | s.-a. | a. |
| 243 | 12 | .09566 | 58.866 | 81.094 | .726 | 19.183 | 112.924 | .238 | s.-a. | a. |
| 244 | 20 | .01460 | 145.587 | 3.724 | 39.095 | 3.268 | 47.574 | .587 | s. | a. |
| 245 | 20 | .02750 | 145.587 | 10.416 | 13.977 | 5.159 | 75.112 | .375 | s. | a. |
| 246 | 20 | .04288 | 145.587 | 21.318 | 6.829 | 7.090 | 103.321 | .291 | s. | a. |
| 247 | 20 | .06113 | 145.587 | 36.643 | 3.973 | 9.018 | 131.299 | .278 | s. | a. |
| 248 | 20 | .08157 | 145.587 | 52.057 | 2.797 | 10.540 | 153.449 | .263 | s.-a. | a. |
| 249 | 30 | .01676 | 299.946 | 3.796 | 79.012 | 2.391 | 71.717 | .695 | s. | a. |
| 250 | 30 | .01221 | 299.946 | 10.189 | 29.438 | 3.706 | 111.173 | .480 | s. | a. |
| 251 | 30 | .04868 | 299.946 | 18.767 | 15.982 | 4.861 | 145.808 | .361 | s. | a. |
| 252 | 40 | .01783 | 499.430 | 4.531 | 110.235 | 2.062 | 103.000 | .617 | s. | a. |

Table 3E

Data and Results for Co-Current Flow of Air and Water
in 1 1/2 Inch Pipe 314 Inches Long With 1 1/4 Inch Orifice for Turbulator

| Run No. | $Q_L$ | $W_G$ | $(\frac{\Delta P}{\Delta \ell})_L \times 10^4$ | $(\frac{\Delta P}{\Delta \ell})_G \times 10^4$ | $X^2$ | $\phi^2$ | $(\frac{\Delta P}{\Delta \ell})_{T-P} \times 10^3$ | $\psi$ | Flow Pattern Upstream | Flow Pattern Downstream |
|---|---|---|---|---|---|---|---|---|---|---|
| 260 | 2 | .01180 | 2.586 | 3.439 | .752 | 18.885 | 4.884 | .098 | p. | w.-a. |
| 261 | 2 | .02138 | 2.586 | 9.815 | .263 | 30.085 | 7.780 | 3.553 | p. | w.-a. |
| 262 | 2 | .03290 | 2.577 | 20.977 | .122 | 42.214 | 10.879 | 2.478 | w. | w.-a. |
| 263 | 2 | .04716 | 2.577 | 39.781 | .064 | 56.086 | 14.455 | 1.953 | w. | w.-a. |
| 264 | 2 | .06413 | 2.577 | 69.095 | .037 | 71.667 | 18.470 | 1.998 | w. | w.-a. |
| 265 | 2 | .08725 | 2.577 | 121.151 | .021 | 91.961 | 23.700 | 2.378 | w.-a. | a. |
| 266 | 6 | .01213 | 17.300 | 3.741 | 4.624 | 8.308 | 14.586 | 5.320 | p. | w.-a. |
| 267 | 6 | .02246 | 17.300 | 10.264 | 1.686 | 13.197 | 22.831 | 2.921 | p. | w.-a. |
| 268 | 6 | .03434 | 17.300 | 21.882 | .787 | 18.509 | 31.866 | 2.294 | s. | a. |
| 269 | 6 | .04804 | 17.300 | 39.844 | .434 | 24.100 | 41.694 | 1.591 | s. | a. |
| 270 | 6 | .06698 | 17.300 | 63.873 | .270 | 29.718 | 51.413 | 1.358 | s.-a. | a. |
| 271 | 6 | .08930 | 17.300 | 102.251 | .169 | 36.623 | 63.358 | 1.468 | s.-a. | a. |
| 272 | 10 | .01244 | 42.233 | 3.691 | 11.441 | 5.639 | 23.815 | 3.802 | p. | w.-a. |
| 273 | 10 | .02349 | 42.233 | 10.583 | 3.990 | 9.001 | 38.011 | 2.189 | s. | a. |
| 274 | 10 | .03574 | 42.233 | 21.129 | 1.999 | 12.236 | 51.669 | 1.846 | s. | a. |
| 275 | 10 | .05132 | 42.233 | 36.004 | 1.173 | 15.503 | 65.465 | 1.332 | s. | a. |
| 276 | 10 | .06972 | 42.233 | 59.754 | .707 | 19.413 | 81.977 | 1.233 | s. | a. |
| 277 | 10 | .09226 | 42.233 | 89.943 | .469 | 23.278 | 98.299 | .996 | s.-a. | a. |
| 278 | 14 | .01273 | 76.707 | 3.648 | 21.024 | 4.304 | 33.014 | 3.149 | s. | a. |
| 279 | 14 | .02398 | 76.707 | 10.527 | 7.286 | 6.889 | 52.848 | 2.042 | s. | a. |
| 280 | 14 | .03769 | 76.157 | 21.083 | 3.612 | 9.408 | 71.649 | 1.516 | s. | a. |
| 281 | 14 | .05287 | 76.157 | 35.152 | 2.166 | 11.805 | 89.905 | 1.404 | s. | a. |
| 282 | 14 | .07231 | 76.157 | 56.184 | 1.355 | 14.538 | 110.717 | 1.001 | s.-a. | a. |
| 283 | 14 | .09506 | 76.157 | 89.354 | .852 | 17.864 | 136.044 | 1.002 | s.-a. | a. |
| 284 | 20 | .01329 | 143.121 | 3.565 | 39.808 | 3.242 | 46.395 | 3.420 | s. | a. |
| 285 | 20 | .02581 | 143.121 | 11.068 | 12.930 | 5.341 | 76.437 | 2.061 | s. | a. |

Table 3E (Concluded)

Data and Results for Co-Current Flow of Air and Water
in 1 1/2 Inch Pipe 314 Inches Long With 1 1/4 Inch Orifice for Turbulator

| Run No. | $Q_L$ | $W_G$ | $(\frac{\Delta P}{\Delta \ell})_L \times 10^4$ | $(\frac{\Delta P}{\Delta \ell})_G \times 10^4$ | $X^2$ | $\phi^2$ | $(\frac{\Delta P}{\Delta \ell})_{T-P} \times 10^3$ | $\psi$ | Flow Pattern Upstream | Flow Pattern Downstream |
|---|---|---|---|---|---|---|---|---|---|---|
| 286 | 20 | .03948 | 143.121 | 21.298 | 7.620 | 7.142 | 102.134 | 1.359 | s. | a. |
| 287 | 20 | .05574 | 143.121 | 36.141 | 3.960 | 9.032 | 129.263 | 1.043 | s. | a. |
| 288 | 20 | .07550 | 143.121 | 57.593 | 2.485 | 11.108 | 158.975 | .837 | s. | a. |
| 289 | 20 | .09673 | 143.121 | 80.136 | 1.786 | 12.862 | 184.088 | .689 | s. | a. |
| 290 | 30 | .01488 | 294.368 | 3.833 | 76.789 | 2.421 | 71.281 | 2.838 | s. | a. |
| 291 | 30 | .02796 | 294.368 | 10.685 | 27.550 | 3.817 | 112.365 | 1.550 | s. | a. |
| 292 | 30 | .04351 | 294.368 | 21.646 | 13.599 | 5.222 | 153.731 | .945 | s. | a. |
| 293 | 30 | .06123 | 293.650 | 35.864 | 8.188 | 6.542 | 192.105 | .818 | s. | a. |
| 294 | 30 | .08245 | 293.650 | 55.601 | 5.281 | 7.948 | 233.391 | .706 | s.-a. | a. |
| 295 | 40 | .01607 | 490.546 | 3.918 | 125.213 | 1.949 | 95.604 | 2.686 | s. | a. |
| 296 | 40 | .03071 | 490.546 | 10.928 | 44.889 | 3.073 | 150.759 | 1.400 | s. | a. |
| 297 | 40 | .04765 | 490.546 | 21.644 | 22.664 | 4.163 | 204.204 | .966 | s. | a. |
| 298 | 40 | .06621 | 490.546 | 35.804 | 13.701 | 5.205 | 255.341 | .820 | s. | a. |
| 299 | 40 | .08879 | 490.546 | 53.744 | 9.128 | 6.234 | 305.799 | .528 | s. | a. |

Table 3F

Data and Results for Co-Current Flow of Air and Water in 1 1 2 Inch Pipe
314 Inches Long With Two Off-Center 1 1 4 Inch Orifices Six Inches Apart for Turbulators

| Run No. | $Q_L$ | $W_G$ | $(\frac{\Delta P}{\Delta \ell})_L \times 10^4$ | $(\frac{\Delta P}{\Delta \ell})_G \times 10^4$ | $X^2$ | $\phi^2$ | $(\frac{\Delta P}{\Delta \ell})_{T\text{-}P} \times 10^3$ | $\psi$ | Flow Pattern Upstream | Flow Pattern Downstream |
|---|---|---|---|---|---|---|---|---|---|---|
| 307 | 2 | .01174 | 2.577 | 3.557 | .724 | 19.200 | 4.948 | 5.982 | w. | w. |
| 308 | 2 | .02179 | 2.570 | 10.485 | .245 | 31.065 | 7.984 | 3.681 | w. | |
| 309 | 2 | .03271 | 2.570 | 21.399 | .120 | 42.642 | 10.959 | 2.434 | w. | w.-a. |
| 310 | 2 | .04603 | 2.570 | 39.286 | .065 | 55.845 | 14.350 | 1.917 | w. | w.-a. |
| 311 | 2 | .06184 | 2.570 | 66.323 | .039 | 70.463 | 18.109 | 1.330 | w. | a. |
| 312 | 2 | .08774 | 2.570 | 124.923 | .021 | 93.335 | 23.988 | 1.200 | w.-a. | a. |
| 313 | 2 | .10085 | 2.570 | 161.858 | .016 | 104.712 | 26.912 | 1.345 | w.-a. | a. |
| 314 | 6 | .01206 | 17.122 | 3.496 | 4.897 | 8.219 | 14.072 | 1.973 | p. | w.-a. |
| 315 | 6 | .02181 | 17.122 | 9.916 | 1.727 | 13.057 | 22.355 | 1.339 | p. | w.-a. |
| 316 | 6 | .03415 | 17.122 | 21.877 | .783 | 18.553 | 31.766 | .791 | s. | a. |
| 317 | 6 | .04859 | 17.122 | 38.717 | .442 | 23.905 | 40.929 | .735 | s. | a. |
| 318 | 6 | .06660 | 17.122 | 68.167 | .251 | 30.730 | 52.615 | .495 | s.-a. | a. |
| 319 | 6 | .08879 | 17.122 | 108.814 | .157 | 37.822 | 64.758 | .537 | s.-a. | a. |
| 320 | 6 | .10672 | 17.122 | 144.053 | .119 | 42.839 | 73.348 | .553 | s.-a. | a. |
| 321 | 10 | .01237 | 41.796 | 3.705 | 11.281 | 5.674 | 23.716 | 1.490 | s. | a. |
| 322 | 10 | .02286 | 41.796 | 10.261 | 4.073 | 8.919 | 37.279 | .987 | s. | a. |
| 323 | 10 | .03486 | 41.796 | 20.379 | 2.051 | 12.096 | 50.557 | .623 | s. | a. |
| 324 | 10 | .04944 | 41.796 | 35.925 | 1.163 | 15.558 | 65.027 | .426 | s. | a. |
| 325 | 10 | .07019 | 41.796 | 64.159 | .651 | 20.128 | 84.125 | .325 | s. | a. |
| 326 | 10 | .09174 | 41.796 | 94.943 | .440 | 23.953 | 100.114 | .392 | s.-a. | a. |
| 327 | 14 | .01265 | 75.444 | 3.676 | 20.521 | 4.350 | 32.821 | 1.349 | s. | a. |
| 328 | 14 | .02382 | 75.444 | 10.571 | 7.137 | 6.954 | 52.460 | .811 | s. | a. |
| 329 | 14 | .03681 | 75.444 | 20.531 | 3.675 | 9.337 | 70.440 | .614 | s. | a. |
| 330 | 14 | .05252 | 75.444 | 37.236 | 2.026 | 12.162 | 91.753 | .548 | s. | a. |
| 331 | 14 | .07183 | 75.444 | 63.044 | 1.197 | 15.365 | 115.918 | .504 | s.-a. | a. |
| 332 | 14 | .09444 | 75.444 | 94.137 | .801 | 18.359 | 138.503 | .394 | s.-a. | a. |

Table 3F (Concluded)

Data and Results for Co-Current Flow of Air and Water in 1 1/2 Inch Pipe
314 Inches Long With Two Off-Center 1 1/4 Inch Orifices Six Inches Apart for Turbulator

| Run No. | $Q_L$ | $W_G$ | $(\frac{\Delta P}{\Delta \ell})_L \times 10^4$ | $(\frac{\Delta P}{\Delta \ell})_G \times 10^4$ | $X^2$ | $\phi^2$ | $(\frac{\Delta P}{\Delta \ell})_{T-P} \times 10^3$ | $\psi$ | Flow Pattern Upstream | Flow Pattern Downstream |
|---|---|---|---|---|---|---|---|---|---|---|
| 333 | 20 | .01350 | 142.177 | 3.749 | 37.924 | 3.312 | 47.092 | 1.370 | s. | a. |
| 334 | 20 | .02568 | 142.177 | 10.508 | 13.530 | 5.234 | 74.419 | .844 | s. | a. |
| 335 | 20 | .03929 | 142.177 | 21.519 | 6.607 | 7.196 | 102.305 | .627 | s. | a. |
| 336 | 20 | .05688 | 142.177 | 38.684 | 3.675 | 9.336 | 132.737 | .598 | s. | a. |
| 337 | 20 | .07512 | 142.177 | 56.126 | 2.533 | 11.013 | 156.587 | .496 | s. | a. |
| 338 | 20 | .09254 | 142.177 | 76.278 | 1.864 | 12.621 | 179.437 | .479 | s.-a. | a. |
| 339 | 30 | .01479 | 293.169 | 3.878 | 75.602 | 2.438 | 71.483 | 1.248 | s. | a. |
| 340 | 30 | .02821 | 293.169 | 10.669 | 27.478 | 3.822 | 112.037 | .818 | s. | a. |
| 341 | 30 | .04380 | 293.169 | 21.489 | 13.642 | 5.215 | 152.890 | .485 | s. | a. |
| 342 | 30 | .06153 | 293.169 | 37.463 | 7.826 | 6.675 | 195.681 | .487 | s. | a. |
| 343 | 30 | .08198 | 293.169 | 56.074 | 5.228 | 7.984 | 234.056 | .314 | s. | a. |
| 344 | 30 | .09354 | 293.169 | 64.927 | 4.515 | 8.521 | 249.796 | .360 | s.-a. | a. |
| 345 | 40 | .01620 | 488.838 | 3.927 | 124.462 | 1.954 | 95.526 | 1.356 | s. | a. |
| 346 | 40 | .03127 | 488.838 | 10.751 | 45.470 | 3.055 | 149.379 | .759 | s. | a. |
| 347 | 40 | .04738 | 488.838 | 20.459 | 23.893 | 4.066 | 198.776 | .533 | s.-a. | a. |
| 348 | 40 | .06762 | 488.838 | 34.415 | 14.204 | 5.122 | 250.407 | .411 | s.-a. | a. |
| 349 | 40 | .08828 | 488.838 | 53.006 | 9.222 | 6.205 | 303.339 | .315 | s.-a. | a. |
| 350 | 40 | .11177 | 488.838 | 72.817 | 6.713 | 7.145 | 349.269 | .223 | s.-a. | a. |

Table 3G

Data and Results for Co-Current Flow of Air and Water in 1 1/2 Inch Pipe 314 Inches Long With Flat Plate Covering Upper Half Pipe Diameter for Turbulator

| Run No. | $Q_L$ | $W_G$ | $(\frac{\Delta P}{\Delta \ell})_L \times 10^4$ | $(\frac{\Delta P}{\Delta \ell})_G \times 10^4$ | $X^2$ | $\phi^2$ | $(\frac{\Delta P}{\Delta \ell})_{T-P} \times 10^3$ | $\psi$ | Flow Pattern Upstream | Flow Pattern Downstream |
|---|---|---|---|---|---|---|---|---|---|---|
| 358 | 2 | .01171 | 2.577 | 3.470 | .743 | 18.989 | 4.894 | .755 | w. | w. |
| 359 | 2 | .02121 | 2.577 | 9.866 | .261 | 30.200 | 7.783 | 1.598 | w. | w. |
| 360 | 2 | .03263 | 2.577 | 21.299 | .120 | 42.500 | 10.953 | 2.175 | w. | w. |
| 361 | 2 | .04677 | 2.577 | 40.547 | .064 | 56.564 | 14.578 | 1.979 | w. | w.-a. |
| 362 | 2 | .06455 | 2.577 | 72.176 | .036 | 73.068 | 18.831 | 1.608 | w.-a. | a. |
| 363 | 2 | .08654 | 2.577 | 115.105 | .022 | 89.894 | 23.167 | 1.787 | w.-a. | a. |
| 364 | 2 | .10935 | 2.577 | 165.863 | .016 | 105.724 | 27.247 | 1.939 | p. | a. |
| 365 | 6 | .01204 | 17.214 | 3.743 | 4.599 | 8.451 | 14.547 | 2.053 | p. | w.-a. |
| 366 | 6 | .02177 | 17.214 | 9.928 | 1.734 | 13.032 | 22.433 | 1.540 | p. | w.-a. |
| 367 | 6 | .03409 | 17.214 | 21.967 | .784 | 18.543 | 31.919 | 1.010 | p. | w.-a. |
| 368 | 6 | .04851 | 17.214 | 41.383 | .416 | 24.564 | 42.283 | .784 | p. | a. |
| 369 | 6 | .06657 | 17.214 | 68.595 | .251 | 30.742 | 52.919 | .638 | s. | a. |
| 370 | 6 | .08961 | 17.214 | 104.633 | .165 | 37.082 | 63.831 | .641 | s. | a. |
| 371 | 10 | .01234 | 42.014 | 3.723 | 11.286 | 5.673 | 23.835 | 1.873 | s. | w.-a. |
| 372 | 10 | .02332 | 42.014 | 10.702 | 3.926 | 9.067 | 38.092 | 1.191 | s. | a. |
| 373 | 10 | .03547 | 42.014 | 21.157 | 1.986 | 12.271 | 51.553 | .751 | s. | a. |
| 374 | 10 | .05016 | 42.014 | 37.209 | 1.129 | 15.767 | 66.240 | .580 | s. | a. |
| 375 | 10 | .06921 | 42.014 | 63.836 | .658 | 20.036 | 84.179 | .645 | s. | a. |
| 376 | 10 | .09252 | 42.014 | 97.505 | .431 | 24.182 | 101.597 | .545 | s.-a. | a. |
| 377 | 14 | .01293 | 75.775 | 3.862 | 19.622 | 4.437 | 33.628 | 1.839 | s. | a. |
| 378 | 14 | .02380 | 75.775 | 10.609 | 7.142 | 6.951 | 52.672 | 1.000 | s. | a. |
| 379 | 14 | .03741 | 75.775 | 22.536 | 3.362 | 9.712 | 73.595 | .737 | s. | a. |
| 380 | 14 | .05323 | 75.775 | 38.307 | 1.978 | 12.292 | 93.142 | .647 | s. | a. |
| 381 | 14 | .07178 | 75.775 | 59.842 | 1.266 | 14.984 | 113.543 | .579 | s.-a. | a. |
| 382 | 14 | .09527 | 75.775 | 96.034 | .789 | 18.486 | 140.077 | .464 | s.-a. | a. |
| 383 | 20 | .01349 | 142.177 | 3.795 | 37.467 | 3.330 | 47.346 | 1.893 | s. | a. |

Table 3G (Concluded)

Data and Results for Co-Current Flow of Air and Water in 1 1/2 Inch
Pipe 314 Inches Long With Flat Plate Covering Upper Half Pipe Diameter for Turbulator

| Run No. | $Q_L$ | $W_G$ | $(\frac{\Delta P}{\Delta \ell})_L \times 10^4$ | $(\frac{\Delta P}{\Delta \ell})_G \times 10^4$ | $X^2$ | $\phi^2$ | $(\frac{\Delta P}{\Delta \ell})_{T-P} \times 10^3$ | $\psi$ | Flow Pattern Upstream | Flow Pattern Downstream |
|---|---|---|---|---|---|---|---|---|---|---|
| 384 | 20 | .02566 | 142.177 | 10.568 | 13.454 | 5.247 | 74.607 | 1.068 | s. | a. |
| 385 | 20 | .03985 | 142.177 | 22.271 | 6.384 | 7.306 | 103.879 | .802 | s. | a. |
| 386 | 20 | .05683 | 142.177 | 38.343 | 3.699 | 9.309 | 132.355 | .604 | s. | a. |
| 387 | 20 | .07665 | 142.177 | 61.387 | 2.316 | 11.461 | 162.942 | .599 | s. | a. |
| 388 | 20 | .09329 | 142.177 | 77.996 | 1.823 | 12.746 | 181.221 | .600 | s.-a. | a. |
| 389 | 30 | .01479 | 291.917 | 3.722 | 78.433 | 2.399 | 70.025 | 1.697 | s. | a. |
| 390 | 30 | .02821 | 291.917 | 10.834 | 26.945 | 3.855 | 112.534 | 1.168 | s. | a. |
| 391 | 30 | .04326 | 291.917 | 21.404 | 13.639 | 5.216 | 152.256 | .786 | s. | a. |
| 392 | 30 | .06217 | 291.917 | 37.095 | 7.869 | 6.658 | 194.363 | .691 | s. | a. |
| 393 | 30 | .08272 | 291.917 | 56.231 | 5.191 | 8.008 | 233.790 | .582 | s.-a. | a. |
| 394 | 40 | .01620 | 488.838 | 3.823 | 127.878 | 1.931 | 94.384 | 1.913 | s. | a. |
| 395 | 40 | .03163 | 488.838 | 10.844 | 45.079 | 3.067 | 149.952 | 1.234 | s. | a. |
| 396 | 40 | .04787 | 488.838 | 21.318 | 22.931 | 4.141 | 202.437 | .836 | s. | a. |
| 397 | 40 | .06762 | 488.838 | 35.179 | 13.896 | 5.173 | 252.860 | .677 | s. | a. |
| 398 | 40 | .08974 | 488.838 | 49.382 | 9.899 | 6.013 | 293.950 | .541 | s. | a. |

Table 3H

Data and Results for Co-Current Flow of Air and Water in 1 1/2 Inch
Pipe 314 Inches Long With Flat Plate Covering Upper Two-Thirds Pipe Diameter for Turbulator

| Run No. | $Q_L$ | $W_G$ | $(\frac{\Delta P}{\Delta \ell})_L \times 10^4$ | $(\frac{\Delta P}{\Delta \ell})_G \times 10^4$ | $X^2$ | $\phi^2$ | $(\frac{\Delta P}{\Delta \ell})_{T-P} \times 10^3$ | $\psi$ | Flow Pattern Upstream | Flow Pattern Downstream |
|---|---|---|---|---|---|---|---|---|---|---|
| 406 | 2 | .01182 | 2.518 | 3.325 | .758 | 18.827 | 4.740 | .482 | w. | w. |
| 407 | 2 | .02142 | 2.518 | 9.489 | .265 | 29.992 | 7.551 | .399 | w. | w.-a. |
| 408 | 2 | .03295 | 2.518 | 19.131 | .132 | 40.944 | 10.309 | .338 | w. | w.-a. |
| 409 | 2 | .04808 | 2.518 | 38.241 | .066 | 55.751 | 14.037 | .368 | w. | a. |
| 410 | 2 | .06612 | 2.518 | 65.322 | .039 | 70.630 | 17.783 | .401 | w. | a. |
| 411 | 2 | .08938 | 2.518 | 109.106 | .023 | 88.697 | 22.332 | .429 | w. | a. |
| 412 | 2 | .10742 | 2.518 | 140.450 | .018 | 99.221 | 24.981 | .505 | w. | a. |
| 413 | 6 | .01210 | 16.863 | 3.425 | 4.923 | 8.199 | 13.827 | .361 | p. | w.-a. |
| 414 | 6 | .02390 | 16.863 | 10.708 | 1.575 | 13.601 | 22.937 | .241 | p. | w.-a. |
| 415 | 6 | .03562 | 16.863 | 19.691 | .856 | 17.826 | 30.060 | .234 | p. | a. |
| 416 | 6 | .04956 | 16.863 | 34.398 | .490 | 22.835 | 38.508 | .231 | p. | a. |
| 417 | 6 | .06957 | 16.863 | 58.643 | .288 | 28.939 | 48.800 | .234 | p. | a. |
| 418 | 6 | .09290 | 16.863 | 96.837 | .174 | 36.157 | 60.972 | .229 | s. | a. |
| 419 | 10 | .01296 | 41.301 | 3.263 | 12.567 | 5.392 | 22.268 | .422 | p. | w.-a. |
| 420 | 10 | .02434 | 41.301 | 9.456 | 4.367 | 8.648 | 35.717 | .283 | p. | a. |
| 421 | 10 | .03875 | 41.301 | 20.456 | 2.019 | 12.181 | 50.308 | .192 | p. | a. |
| 422 | 10 | .05410 | 41.301 | 34.766 | 1.188 | 15.415 | 63.665 | .192 | p. | a. |
| 423 | 10 | .07525 | 41.301 | 54.907 | .752 | 18.883 | 77.987 | .208 | s. | a. |
| 424 | 10 | .09906 | 41.301 | 76.941 | .537 | 21.934 | 90.590 | .221 | s. | a. |
| 425 | 14 | .01404 | 74.749 | 3.358 | 22.259 | 4.916 | 31.366 | .396 | p. | a. |
| 426 | 14 | .02656 | 74.749 | 9.491 | 7.877 | 6.655 | 49.755 | .263 | p. | a. |
| 427 | 14 | .04612 | 74.749 | 19.806 | 3.774 | 9.227 | 68.969 | .220 | p. | a. |
| 428 | 14 | .05826 | 74.749 | 32.837 | 2.276 | 11.549 | 86.327 | .204 | s. | a. |
| 429 | 14 | .07904 | 74.749 | 48.667 | 1.536 | 14.153 | 102.804 | .201 | s. | a. |
| 430 | 14 | .09149 | 74.749 | 63.122 | 1.184 | 15.437 | 115.388 | .188 | s. | a. |
| 431 | 20 | .01577 | 140.910 | 3.787 | 37.206 | 3.340 | 47.070 | .456 | s. | a. |

Table 3H (Concluded)

Data and Results for Co-Current Flow of Air and Water in 1 1/2 Inch Pipe 314 Inches Long With Flat Plate Covering Upper Two-Thirds Pipe Diameter for Turbulator

| Run No. | $Q_L$ | $W_G$ | $(\frac{\Delta P}{\Delta \ell})_L \times 10^4$ | $(\frac{\Delta P}{\Delta \ell})_G \times 10^4$ | $X^2$ | $\phi^2$ | $(\frac{\Delta P}{\Delta \ell})_{T-P} \times 10^3$ | $\psi$ | Flow Pattern Upstream | Flow Pattern Downstream |
|---|---|---|---|---|---|---|---|---|---|---|
| 432 | 20 | .03095 | 140.910 | 9.879 | 14.263 | 5.113 | 72.048 | .305 | s. | a. |
| 433 | 20 | .04457 | 140.910 | 16.696 | 8.440 | 6.455 | 90.951 | .254 | s. | a. |
| 434 | 20 | .06349 | 140.910 | 28.682 | 4.913 | 8.207 | 115.650 | .194 | s. | a. |

Table 3I

Data and Results for Co-Current Flow of Air and Water
in 1 1/2 Inch Pipe 314 Inches Long With Segmented Orifice for Turbulator

| Run No. | $Q_L$ | $W_G$ | $(\frac{\Delta P}{\Delta \ell})_L \times 10^4$ | $(\frac{\Delta P}{\Delta \ell})_G \times 10^4$ | $X^2$ | $\phi^2$ | $(\frac{\Delta P}{\Delta \ell})_{T-P} \times 10^3$ | $\psi$ | Flow Pattern Upstream | Flow Pattern Downstream |
|---|---|---|---|---|---|---|---|---|---|---|
| 442 | 2 | .01178 | 2.577 | 3.525 | .731 | 19.122 | 4.928 | 4.256 | st.-w. | w. |
| 443 | 2 | .02133 | 2.577 | 9.992 | .258 | 30.370 | 7.827 | 3.171 | st.-w. | w. |
| 444 | 2 | .03282 | 2.577 | 21.403 | .120 | 42.592 | 10.977 | 2.421 | w. | w. |
| 445 | 2 | .04618 | 2.577 | 39.186 | .066 | 55.713 | 14.358 | 1.729 | w. | w. |
| 446 | 2 | .06492 | 2.577 | 72.234 | .036 | 73.095 | 18.838 | 1.477 | w. | a. |
| 447 | 2 | .08704 | 2.577 | 123.035 | .021 | 92.593 | 23.863 | 1.371 | w.-a. | a. |
| 448 | 2 | .10596 | 2.577 | 165.241 | .016 | 105.537 | 27.199 | 1.550 | w.-a. | a. |
| 449 | 6 | .01212 | 17.201 | 3.518 | 4.889 | 8.225 | 14.148 | 2.466 | p. | w.-a. |
| 450 | 6 | .02244 | 17.201 | 10.374 | 1.658 | 13.294 | 22.867 | 1.481 | p. | w.-a. |
| 451 | 6 | .03361 | 17.201 | 21.237 | .810 | 18.272 | 31.430 | 1.034 | p. | w.-a. |
| 452 | 6 | .04883 | 17.201 | 38.603 | .446 | 23.825 | 40.980 | .674 | s. | a. |
| 453 | 6 | .06600 | 17.201 | 62.706 | .274 | 29.551 | 50.831 | .624 | s. | a. |
| 454 | 6 | .08923 | 17.201 | 102.258 | .168 | 36.717 | 63.158 | .527 | s.-a. | a. |
| 455 | 6 | .10244 | 17.201 | 131.992 | .130 | 41.123 | 70.737 | .514 | s.-a. | a. |
| 456 | 10 | .01242 | 42.013 | 3.505 | 11.986 | 5.524 | 23.207 | 1.961 | s. | w.-a. |
| 457 | 10 | .02345 | 42.013 | 10.626 | 3.954 | 9.038 | 37.973 | .872 | s. | a. |
| 458 | 10 | .03640 | 42.013 | 22.027 | 1.907 | 12.492 | 52.484 | .805 | s. | a. |
| 459 | 10 | .05124 | 42.013 | 38.233 | 1.099 | 15.958 | 67.044 | .500 | s. | a. |
| 460 | 10 | .06961 | 42.013 | 62.948 | .667 | 19.912 | 83.657 | .381 | s. | a. |
| 461 | 10 | .09211 | 42.013 | 96.156 | .437 | 24.033 | 100.971 | .537 | s.-a. | a. |
| 462 | 14 | .01271 | 75.971 | 3.484 | 21.808 | 4.235 | 32.170 | 1.649 | s. | w.-a. |
| 463 | 14 | .02392 | 75.971 | 10.669 | 7.120 | 6.961 | 52.880 | .971 | s. | a. |
| 464 | 14 | .03696 | 75.971 | 20.476 | 3.710 | 9.297 | 70.631 | .561 | s. | a. |
| 465 | 14 | .05274 | 75.971 | 35.189 | 2.159 | 11.823 | 89.825 | .503 | s. | a. |
| 466 | 14 | .07297 | 75.971 | 60.627 | 1.253 | 15.054 | 114.367 | .402 | s.-a. | a. |
| 467 | 14 | .09482 | 75.971 | 89.472 | .849 | 17.893 | 135.939 | .363 | s.-a. | a. |

Table 3I (Concluded)

Data and Results for Co-Current Flow of Air and Water
in 1 1/2 Inch Pipe 314 Inches Long With Segmented Orifice for Turbulator

| Run No. | $Q_L$ | $W_G$ | $(\frac{\Delta P}{\Delta \ell})_L \times 10^4$ | $(\frac{\Delta P}{\Delta \ell})_G \times 10^4$ | $X^2$ | $\phi^2$ | $(\frac{\Delta P}{\Delta \ell})_{T-P} \times 10^3$ | $\psi$ | Flow Pattern Upstream | Flow Pattern Downstream |
|---|---|---|---|---|---|---|---|---|---|---|
| 468 | 20 | .01357 | 142.817 | 3.521 | 40.562 | 3.215 | 45.912 | 1.246 | s. | a. |
| 469 | 20 | .02581 | 142.781 | 10.528 | 13.561 | 5.229 | 74.659 | .853 | s. | a. |
| 470 | 20 | .04008 | 142.781 | 22.198 | 6.432 | 7.282 | 103.971 | .643 | s. | a. |
| 471 | 20 | .05716 | 142.781 | 36.892 | 3.870 | 9.194 | 130.276 | .602 | s.-a. | a. |
| 472 | 20 | .07550 | 142.781 | 55.851 | 2.556 | 10.969 | 156.615 | .436 | s.-a. | a. |
| 473 | 20 | .10026 | 142.781 | 80.591 | 1.772 | 12.908 | 184.307 | .407 | s.-a. | a. |
| 474 | 20 | .11974 | 142.781 | 104.358 | 1.368 | 14.478 | 206.717 | .379 | s.-a. | a. |
| 475 | 30 | .01485 | 293.687 | 3.894 | 75.412 | 2.441 | 71.689 | 1.267 | s. | a. |
| 476 | 30 | .02833 | 293.687 | 11.200 | 26.222 | 3.902 | 114.591 | .770 | s. | a. |
| 477 | 30 | .04398 | 293.687 | 20.804 | 14.117 | 5.136 | 150.852 | .584 | s. | a. |
| 478 | 30 | .06178 | 293.687 | 34.755 | 8.450 | 6.451 | 189.456 | .539 | s. | a. |
| 479 | 30 | .08231 | 293.687 | 54.357 | 5.403 | 7.868 | 231.074 | .359 | s.-a. | a. |
| 480 | 40 | .01654 | 490.821 | 3.867 | 126.911 | 1.937 | 95.087 | 1.386 | s. | a. |
| 481 | 40 | .03073 | 490.821 | 10.384 | 47.269 | 3.004 | 147.422 | .848 | s. | a. |
| 482 | 40 | .04818 | 490.821 | 21.012 | 23.359 | 4.107 | 201.597 | .581 | s. | a. |
| 483 | 40 | .06747 | 490.821 | 34.233 | 14.338 | 5.101 | 250.380 | .492 | s. | a. |
| 484 | 40 | .08886 | 490.821 | 50.033 | 9.810 | 6.037 | 296.331 | .349 | s.-a. | a. |

Table 3J

Data and Results for Co-Current Flow of Air and Water
in 1 1/2 Inch Pipe 314 Inches Long With Spiral Coil for Turbulator

| Run No. | $Q_L$ | $W_G$ | $(\frac{\Delta P}{\Delta \ell})_L \times 10^4$ | $(\frac{\Delta P}{\Delta \ell})_G \times 10^4$ | $X^2$ | $\phi^2$ | $(\frac{\Delta P}{\Delta \ell})_{T-P} \times 10^3$ | $\psi$ | Flow Pattern Upstream | Flow Pattern Downstream |
|---|---|---|---|---|---|---|---|---|---|---|
| 492 | 2 | .01183 | 2.563 | 3.457 | .741 | 19.006 | 4.870 | 2.415 | st. | w. |
| 493 | 2 | .02143 | 2.563 | 9.859 | .260 | 30.267 | 7.756 | 3.834 | w. | w. |
| 494 | 2 | .03298 | 2.563 | 20.885 | .123 | 42.238 | 10.824 | 1.231 | w. | w. |
| 495 | 2 | .04641 | 2.563 | 38.575 | .066 | 55.468 | 14.212 | 1.784 | w. | w.-a. |
| 496 | 2 | .06429 | 2.563 | 69.246 | .037 | 71.918 | 18.429 | 1.662 | w. | a. |
| 497 | 2 | .08847 | 2.563 | 115.655 | .022 | 90.312 | 23.143 | 1.986 | w.-a. | a. |
| 498 | 2 | .10852 | 2.563 | 158.634 | .016 | 103.915 | 36.629 | 2.637 | w.-a. | a. |
| 499 | 6 | .01216 | 17.167 | 3.487 | 4.924 | 8.199 | 14.077 | 3.875 | p. | w.-a. |
| 500 | 6 | .02199 | 17.167 | 9.864 | 1.740 | 13.011 | 22.338 | 2.372 | p. | w.-a. |
| 501 | 6 | .03443 | 17.167 | 21.841 | .786 | 18.517 | 31.791 | 1.577 | s. | a. |
| 502 | 6 | .04899 | 17.167 | 38.441 | .447 | 23.792 | 40.848 | 1.158 | s. | a. |
| 503 | 6 | .06715 | 17.167 | 63.772 | .269 | 29.798 | 51.159 | .947 | s.-a. | a. |
| 504 | 6 | .08952 | 17.167 | 102.080 | .168 | 36.719 | 63.043 | 1.020 | s.-a. | a. |
| 505 | 6 | .11726 | 17.167 | 168.274 | .101 | 45.898 | 78.801 | 1.030 | s.-a. | a. |
| 506 | 10 | .01246 | 42.123 | 3.699 | 11.386 | 5.651 | 23.804 | 2.887 | p. | w.-a. |
| 507 | 10 | .02303 | 42.123 | 10.244 | 4.112 | 8.882 | 37.414 | 1.888 | p. | w.-a. |
| 508 | 10 | .03580 | 42.123 | 21.109 | 1.996 | 12,224 | 51.576 | 1.283 | s. | a. |
| 509 | 10 | .05141 | 42.123 | 38.044 | 1.107 | 15.904 | 66.994 | .865 | s. | a. |
| 510 | 10 | .06984 | 42.123 | 66.149 | .637 | 20.332 | 85.645 | .544 | s. | a. |
| 511 | 10 | .09242 | 42.123 | 99.110 | .425 | 24.329 | 102.486 | .531 | s.-a. | a. |
| 512 | 14 | .01276 | 76.157 | 3.416 | 22.294 | 4.193 | 31.935 | 2.120 | s. | a. |
| 513 | 14 | .02450 | 76.157 | 10.991 | 6.929 | 7.045 | 53.655 | 1.717 | s. | a. |
| 514 | 14 | .03775 | 76.157 | 22.348 | 3.408 | 9.655 | 73.528 | 1.055 | s. | a. |
| 515 | 14 | .05296 | 76.157 | 36.690 | 2.076 | 12.032 | 91.632 | .719 | s. | a. |
| 516 | 14 | .07158 | 76.157 | 60.859 | 1.251 | 12.063 | 114.717 | .715 | s. | a. |
| 517 | 14 | .09522 | 76.157 | 98.581 | .773 | 18.660 | 142.111 | .674 | s.-a. | a. |

Table 3J (Concluded)

Data and Results for Co-Current Flow of Air and Water
in 1 1/2 Inch Pipe 314 Inches Long With Spiral Coil for Turbulator

| Run No. | $Q_L$ | $W_G$ | $(\frac{\Delta P}{\Delta \ell})_L \times 10^4$ | $(\frac{\Delta P}{\Delta \ell})_G \times 10^4$ | $X^2$ | $\phi^2$ | $(\frac{\Delta P}{\Delta \ell})_{T\text{-}P} \times 10^3$ | $\psi$ | Flow Pattern Upstream | Flow Pattern Downstream |
|---|---|---|---|---|---|---|---|---|---|---|
| 518 | 20 | .01359 | 143.478 | 3.939 | 36.421 | 3.372 | 48.384 | 2.067 | s. | a. |
| 519 | 20 | .02493 | 143.478 | 10.237 | 14.015 | 5.153 | 73.935 | 1.122 | s. | a. |
| 520 | 20 | .03954 | 143.478 | 21.225 | 6.760 | 7.123 | 102.199 | .882 | s. | a. |
| 521 | 20 | .05583 | 143.478 | 36.033 | 3.982 | 9.010 | 129.270 | .680 | s. | a. |
| 522 | 20 | .07643 | 143.478 | 56.972 | 2.518 | 11.042 | 158.430 | .844 | s.-a. | a. |
| 523 | 20 | .09398 | 143.478 | 79.348 | 1.808 | 12.792 | 183.535 | .574 | s.-a. | a. |
| 524 | 30 | .01647 | 294.368 | 3.660 | 80.418 | 2.372 | 69.834 | 1.542 | s. | a. |
| 525 | 30 | .02764 | 294.368 | 10.157 | 28.982 | 3.732 | 109.864 | .598 | s. | a. |
| 526 | 30 | .04365 | 294.368 | 20.904 | 14.082 | 5.142 | 151.370 | .879 | s. | a. |
| 527 | 30 | .06143 | 294.368 | 35.873 | 8.206 | 6.535 | 192.385 | .596 | s. | a. |
| 528 | 30 | .08346 | 294.368 | 55.985 | 5.258 | 7.964 | 234.423 | .374 | s.-a. | a. |
| 529 | 30 | .09263 | 294.368 | 63.984 | 4.601 | 8.450 | 248.744 | .504 | s.-a. | a. |
| 530 | 40 | .01613 | 492.841 | 3.745 | 131.593 | 1.906 | 93.955 | 1.978 | s. | a. |
| 531 | 40 | .03045 | 492.841 | 10.645 | 46.297 | 3.031 | 149.401 | .953 | s. | a. |
| 532 | 40 | .04785 | 492.841 | 21.520 | 22.902 | 4.145 | 204.201 | .611 | s. | a. |
| 533 | 40 | .06710 | 492.841 | 35.042 | 14.064 | 5.145 | 253.569 | .557 | s. | a. |
| 534 | 40 | .08777 | 492.841 | 51.993 | 9.479 | 6.130 | 302.119 | .350 | s. | a. |
| 535 | 40 | .11673 | 492.841 | 77.022 | 6.399 | 7.299 | 359.713 | .352 | s. | a. |

Table 3K

Data and Results for Co-Current Flow of Air and Water
in 1 1/2 Inch Pipe 314 Inches Long With Propeller for Turbulator

| Run No. | $Q_L$ | $W_G$ | $(\frac{\Delta P}{\Delta \ell})_L \times 10^4$ | $(\frac{\Delta P}{\Delta \ell})_G \times 10^4$ | $X^2$ | $\phi^2$ | $(\frac{\Delta P}{\Delta \ell})_{T-P} \times 10^3$ | $\psi$ | Flow Pattern Upstream | Flow Pattern Downstream |
|---|---|---|---|---|---|---|---|---|---|---|
| 543 | 2 | .01180 | 2.532 | 3.462 | .731 | 19.121 | 4.841 | .991 | p. | w.-a. |
| 544 | 2 | .02192 | 2.532 | 10.311 | .245 | 31.042 | 7.859 | 1.529 | w. | s.-a. |
| 545 | 2 | .03290 | 2.532 | 21.193 | .119 | 42.744 | 10.821 | 1.384 | w. | s.-a. |
| 546 | 2 | .04716 | 2.532 | 40.444 | .063 | 56.949 | 14.418 | 1.368 | w. | a. |
| 547 | 2 | .06508 | 2.532 | 72.130 | .035 | 73.628 | 18.640 | 1.193 | w. | a. |
| 548 | 2 | .08625 | 2.532 | 112.262 | .023 | 89.607 | 22.686 | 1.160 | w.-a. | a. |
| 549 | 2 | .11124 | 2.532 | 159.577 | .016 | 104.751 | 26.520 | 1.628 | w.-a. | a. |
| 550 | 6 | .01212 | 17.115 | 3.782 | 4.525 | 8.512 | 14.569 | 2.004 | p. | w.-a. |
| 551 | 6 | .02244 | 17.122 | 10.404 | 1.646 | 13.337 | 22.837 | 1.250 | p. | w.-a. |
| 552 | 6 | .03432 | 17.122 | 21.952 | .780 | 18.581 | 31.814 | .713 | s. | a. |
| 553 | 6 | .04800 | 17.122 | 37.560 | .456 | 23.587 | 40.384 | .605 | s. | a. |
| 554 | 6 | .06693 | 17.122 | 64.823 | .264 | 30.051 | 51.453 | .612 | s. | a. |
| 555 | 6 | .08923 | 17.122 | 103.427 | .166 | 36.979 | 63.314 | .564 | s.-a. | a. |
| 556 | 10 | .01243 | 41.912 | 3.515 | 11.923 | 5.536 | 23.205 | 1.643 | s. | a. |
| 557 | 10 | .02297 | 41.907 | 9.753 | 4.297 | 8.710 | 36.502 | 1.058 | s. | a. |
| 558 | 10 | .03571 | 41.907 | 21.036 | 2.092 | 11.991 | 50.252 | .642 | s. | a. |
| 559 | 10 | .05128 | 41.907 | 34.424 | 1.217 | 15.248 | 63.902 | .515 | s. | a. |
| 560 | 10 | .06967 | 41.907 | 61.163 | .685 | 19.681 | 82.479 | .601 | s. | a. |
| 561 | 10 | .09313 | 41.907 | 93.968 | .446 | 23.816 | 99.804 | .525 | s.-a. | a. |
| 562 | 14 | .01273 | 75.775 | 3.491 | 21.704 | 4.244 | 32.156 | 1.373 | s. | a. |
| 563 | 14 | .02396 | 75.775 | 10.184 | 7.441 | 6.826 | 51.723 | 1.023 | s. | a. |
| 564 | 14 | .03766 | 75.775 | 20.401 | 3.714 | 9.292 | 70.413 | .717 | s. | a. |
| 565 | 14 | .05358 | 75.775 | 36.590 | 2.071 | 12.044 | 91.265 | .533 | s. | a. |

Table 3L

Data and Results for Co-Current Flow of Air and Water
in 1 1/2 Inch Pipe 314 Inches Long With Packed Section for Turbulator

| Run No. | $Q_L$ | $W_G$ | $(\frac{\Delta P}{\Delta \ell})_L \times 10^4$ | $(\frac{\Delta P}{\Delta \ell})_G \times 10^4$ | $X^2$ | $\phi^2$ | $(\frac{\Delta P}{\Delta \ell})_{T-P} \times 10^3$ | $\psi$ | Flow Pattern Upstream | Flow Pattern Downstream |
|---|---|---|---|---|---|---|---|---|---|---|
| 572 | 2 | .01176 | 2.595 | 3.515 | .738 | 19.042 | 4.941 | .306 | st. | w. |
| 573 | 2 | .02184 | 2.595 | 10.650 | .244 | 31.149 | 8.082 | .440 | w. | w.-f. |
| 574 | 2 | .03420 | 2.595 | 22.211 | .117 | 43.168 | 11.201 | .413 | w. | w.-a. |
| 575 | 2 | .04784 | 2.595 | 38.216 | .068 | 54.930 | 14.253 | .400 | w. | a. |
| 576 | 2 | .06579 | 2.595 | 65.276 | .040 | 69.670 | 18.078 | .457 | w. | a. |
| 577 | 2 | .08990 | 2.595 | 105.359 | .025 | 86.171 | 22.360 | .527 | w.-a. | a. |
| 578 | 6 | .01240 | 17.300 | 3.564 | 4.855 | 8.251 | 14.274 | .399 | p. | f. |
| 579 | 6 | .02341 | 17.300 | 10.299 | 1.680 | 13.217 | 22.866 | .280 | s. | f.-a. |
| 580 | 6 | .03495 | 17.300 | 20.354 | .850 | 17.885 | 30.942 | .296 | s. | a. |
| 581 | 6 | .05036 | 17.300 | 37.442 | .462 | 23.444 | 40.559 | .259 | s. | a. |
| 582 | 6 | .06949 | 17.300 | 62.173 | .278 | 29.364 | 50.801 | .282 | s. | a. |
| 583 | 6 | .09383 | 17.300 | 95.612 | .181 | 35.547 | 61.498 | .305 | s.-a. | a. |
| 584 | 10 | .01354 | 42.228 | 3.710 | 11.384 | 5.652 | 23.865 | .467 | s. | f.-a. |
| 585 | 10 | .02577 | 42.228 | 10.539 | 4.007 | 8.985 | 37.941 | .348 | s. | f.-a. |
| 586 | 10 | .03942 | 42.228 | 19.867 | 2.126 | 11.905 | 50.275 | .322 | s. | a. |
| 587 | 10 | .05565 | 42.228 | 35.880 | 1.177 | 15.479 | 65.365 | .279 | s. | a. |
| 588 | 10 | .07617 | 42.228 | 52.700 | .801 | 18.360 | 77.530 | .288 | s. | a. |
| 589 | 10 | .10010 | 42.228 | 78.622 | .537 | 21.929 | 92.599 | .269 | s.-a. | a. |
| 590 | 14 | .01434 | 76.157 | 3.559 | 21.397 | 4.270 | 32.523 | .550 | s. | f.-a. |
| 591 | 14 | .02792 | 76.157 | 10.067 | 7.565 | 6.776 | 51.603 | .356 | s. | f.-a. |
| 592 | 14 | .04233 | 76.157 | 20.725 | 3.675 | 9.337 | 71.106 | .295 | s. | a. |
| 593 | 14 | .05981 | 76.157 | 33.535 | 2.271 | 11.561 | 88.045 | .272 | s. | a. |
| 594 | 14 | .08082 | 76.157 | 51.424 | 1.481 | 13.977 | 106.449 | .264 | s. | a. |
| 595 | 20 | .01604 | 143.478 | 37.666 | 38.092 | 3.306 | 47.429 | .581 | s. | f.-a. |
| 596 | 20 | .03066 | 143.478 | 10.179 | 14.096 | 5.140 | 73.746 | .388 | s. | f.-a. |

# CHAPTER V

## CONCLUSIONS

The conclusions resulting from the investigation of the effect of turbulators on flow patterns and pressure drops in two-phase gas-liquid flow may be summarized as follows:

1. Certain types of turbulators, when placed in a piping system where two-phase flow occurs, produced temporary changes in the prevalent flow pattern in the system. This change was generally the transformation of a wave, plug, slug, or slug-annular flow pattern to an annular flow pattern.

2. The length downstream of the turbulator for which the transformed flow pattern existed was found to be a function of the equivalent length of the turbulator and the gas and liquid flow rates.

3. The pressure drops across the various turbulators could be predicted satisfactorily for values of $X^2$ greater than about 3 by using the correlation of Gossage (3).

# APPENDICES

# APPENDIX I

## BASIC DATA FROM ALL RUNS

Table 4 includes the basic experimental data from all runs made in these tests.

Table 4A

Data for Co-Current Flow of Air and Water
in 1 1/2 Inch Test Section 314 Inches Long With No Turbulator

| Run No. | $Q_L$ (GPM) | $W_G$ (lb/sec) | $T_L$ (°C) | $T_G$ (°C) | $(\Delta P)_{exp}$ (in.Hg) | $P_1$ (psig) |
|---|---|---|---|---|---|---|
| 1 | 2 | | 30 | | 0 | 0 |
| 2 | 4 | | 30 | | 0 | 0 |
| 3 | 6 | | 30 | | 0 | 0 |
| 4 | 8 | | 30 | | .10 | 0 |
| 5 | 10 | | 30 | | .16 | 0 |
| 6 | 12 | | 30 | | .29 | 0 |
| 7 | 14 | | 30 | | .38 | 0 |
| 8 | 20 | | 30 | | .75 | 1 |
| 9 | 30 | | 30 | | 1.60 | 2 |
| 10 | 40 | | 30 | | 2.96 | 4 |
| 11 | 50 | | 30 | | 4.35 | 5 |
| 12 | 2 | .01127 | 31 | 33 | 0 | 0 |
| 13 | 2 | .02127 | 31 | 33 | .35 | 0 |
| 14 | 2 | .03274 | 31 | 33 | .84 | 0 |
| 15 | 2 | .04607 | 31 | 33 | 1.41 | 0 |
| 16 | 2 | .06286 | 31 | 33 | 2.18 | 0 |
| 17 | 4 | .01206 | 33 | 33 | 1.98 | 0 |
| 18 | 4 | .02181 | 33 | 33 | 2.18 | 0 |
| 19 | 4 | .03274 | 33 | 33 | 2.18 | 0 |
| 20 | 4 | .04693 | 33 | 33 | 2.38 | 0 |
| 21 | 4 | .06476 | 33 | 33 | 2.79 | 1 |
| 22 | 4 | .08353 | 33 | 33 | 3.40 | 2 |
| 23 | 6 | .01177 | 34 | 32 | 2.18 | 0 |
| 24 | 6 | .02185 | 34 | 32 | 2.79 | 0 |
| 25 | 6 | .03420 | 34 | 32 | 2.79 | 1 |
| 26 | 6 | .04867 | 34 | 32 | 3.19 | 1 |
| 27 | 6 | .06579 | 34 | 32 | 3.98 | 2 |
| 28 | 6 | .08560 | 34 | 32 | 4.35 | 3 |
| 29 | 8 | .01209 | 34 | 31.5 | 2.79 | 1 |
| 30 | 8 | .02289 | 34 | 31.5 | 3.38 | 2 |
| 31 | 8 | .03492 | 34 | 31.5 | 3.75 | 2 |
| 32 | 8 | .04871 | 34 | 31.5 | 3.98 | 3 |
| 33 | 8 | .06766 | 34 | 31.5 | 4.94 | 3 |
| 34 | 8 | .09188 | 34 | 31.5 | 5.72 | 4 |
| 35 | 10 | .01239 | 35 | 31.5 | 3.18 | 2 |
| 36 | 10 | .02339 | 35 | 31.5 | 3.76 | 2 |
| 37 | 10 | .03559 | 35 | 31.5 | 4.54 | 3 |
| 38 | 10 | .03559 | 35 | 31.5 | 4.54 | 3 |

Table 4A (Concluded)

Data for Co-Current Flow of Air and Water
in 1 1/2 Inch Test Section 314 Inches Long With No Turbulator

| Run No. | $Q_L$ (GPM) | $W_G$ (lb/sec) | $T_L$ (°C) | $T_G$ (°C) | $(\Delta P)_{exp}$ (in. Hg) | $P_1$ (psig) |
|---|---|---|---|---|---|---|
| 39 | 10 | .06944 | 35 | 31.5 | 6.50 | 5 |
| 40 | 10 | .09282 | 35 | 31.5 | 7.10 | 6 |
| 41 | 12 | .01240 | 35 | 31 | 4.15 | 2 |
| 42 | 12 | .02341 | 35 | 31 | 4.95 | 3 |
| 43 | 12 | .03693 | 35 | 31 | 5.72 | 3 |
| 44 | 12 | .05193 | 35 | 31 | 6.70 | 5 |
| 45 | 12 | .06772 | 35 | 31 | 7.10 | 6 |
| 46 | 12 | .09290 | 35 | 28 | 8.26 | 7 |
| 47 | 14 | .01276 | 36 | 28 | 4.53 | 2 |
| 48 | 14 | .02402 | 36 | 28 | 5.10 | 3 |
| 49 | 14 | .03711 | 36 | 28 | 6.30 | 4 |
| 50 | 14 | .05296 | 36 | 28 | 7.30 | 5 |
| 51 | 14 | .07071 | 36 | 28 | 8.08 | 6 |
| 52 | 14 | .09522 | 36 | 28 | 9.22 | 7 |
| 53 | 20 | .01333 | 36 | 28 | 5.30 | 3 |
| 54 | 20 | .02497 | 36 | 28 | 6.50 | 5 |
| 55 | 20 | .03961 | 36 | 28 | 8.26 | 6 |
| 56 | 20 | .05592 | 36 | 28 | 9.62 | 8 |
| 57 | 20 | .07655 | 36 | 28 | 10.58 | 9 |
| 58 | 20 | .0883 | 36 | 28 | 11.75 | 12 |
| 59 | 30 | .01437 | 35 | 30 | 7.50 | 6 |
| 60 | 30 | .02755 | 35 | 30 | 9.03 | 8 |
| 61 | 30 | .04300 | 35 | 30 | 10.20 | 9 |
| 62 | 30 | .06123 | 35 | 30 | 12.50 | 13 |
| 63 | 30 | .08245 | 35 | 30 | 14.45 | 16 |
| 64 | 40 | .01608 | 35 | 30 | 10.20 | 10 |
| 65 | 40 | .03732 | 35 | 30 | 12.12 | 13 |
| 66 | 40 | .04616 | 35 | 30 | 15.63 | 15 |
| 67 | 40 | .06627 | 35 | 30 | 17.05 | 18 |
| 68 | 40 | .08886 | 35 | 30 | 18.83 | 22 |
| 69 | 40 | .11254 | 35 | 30 | 20.82 | 26 |

Table 4B

Data for Co-Current Flow of Air and Water in 1 1/2 Inch Test Section 314 Inches Long With Wire Gauze for Turbulator

| Run No. | $Q_L$ | $W_G$ | $T_L$ | $T_G$ | $(\Delta P)_{exp}$ | $P_1$ |
|---|---|---|---|---|---|---|
| | (GPM) | (lb/sec) | (°C) | (°C) | (in. Hg) | (psig) |
| 70 | 2 | | 31 | | 0 | 0 |
| 71 | 4 | | 31 | | 0 | 0 |
| 72 | 6 | | 31 | | .05 | 0 |
| 73 | 8 | | 31 | | .25 | 0 |
| 74 | 10 | | 31 | | .32 | 0 |
| 75 | 12 | | 31 | | .54 | 0 |
| 76 | 14 | | 31 | | .78 | 0 |
| 77 | 20 | | 31 | | 1.75 | 1 |
| 78 | 30 | | 31 | | 3.95 | 3 |
| 79 | 40 | | 31 | | 7.60 | 5 |
| 80 | 50 | | 31 | | 11.93 | 9 |
| 81 | 2 | .01182 | 29.5 | 29 | 1.00 | 0 |
| 82 | 2 | .02141 | 29.5 | 29 | 2.00 | 0 |
| 83 | 2 | .03367 | 29.5 | 29 | 2.50 | 0 |
| 84 | 2 | .04808 | 29.5 | 29 | 2.78 | 0 |
| 85 | 2 | .06230 | 29.5 | 29 | 3.36 | 1 |
| 86 | 2 | .08839 | 29.5 | 29 | 4.15 | 2 |
| 87 | 4 | .01182 | 31 | 29 | 2.18 | 0 |
| 88 | 4 | .02195 | 31 | 29 | 2.57 | 0 |
| 89 | 4 | .03367 | 31 | 29 | 2.80 | 0 |
| 90 | 4 | .04891 | 31 | 29 | 3.36 | 1 |
| 91 | 4 | .06612 | 31 | 29 | 3.83 | 2 |
| 92 | 4 | .08938 | 31 | 29 | 4.92 | 2 |
| 93 | 6 | .01214 | 31 | 29 | 3.18 | 1 |
| 94 | 6 | .02195 | 31 | 29 | 3.56 | 1 |
| 95 | 6 | .03437 | 31 | 29 | 3.18 | 1 |
| 96 | 6 | .04973 | 31 | 29 | 4.53 | 2 |
| 97 | 6 | .06974 | 31 | 29 | 4.93 | 2 |
| 98 | 6 | .08937 | 31 | 29 | 5.72 | 3 |
| 99 | 8 | .01244 | 32 | 29 | 3.75 | 1 |
| 100 | 8 | .02248 | 32 | 29 | 3.95 | 2 |
| 101 | 8 | .03574 | 32 | 29 | 4.53 | 3 |
| 102 | 8 | .05053 | 32 | 29 | 4.92 | 4 |
| 103 | 8 | .06972 | 32 | 29 | 6.90 | 5 |
| 104 | 8 | .09226 | 32 | 29 | 7.68 | 5 |
| 105 | 10 | .01244 | 33 | 29 | 3.95 | 1 |
| 106 | 10 | .02398 | 33 | 29 | 5.12 | 3 |
| 107 | 10 | .03690 | 33 | 29 | 6.10 | 4 |

Table 4B (Concluded)

Data for Co-Current Flow of Air and Water in 1 1/2 Inch Test Section 314 Inches Long With Wire Gauze for Turbulator

| Run No. | $Q_L$ (GPM) | $W_G$ (lb/sec) | $T_L$ (°C) | $T_G$ (°C) | $(\Delta P)_{exp}$ (in. Hg) | $P_1$ (psig) |
|---|---|---|---|---|---|---|
| 108 | 10 | .05210 | 33 | 29 | 6.50 | 4 |
| 109 | 10 | .06972 | 33 | 29 | 7.28 | 6 |
| 110 | 10 | .09321 | 33 | 29 | 8.83 | 7 |
| 111 | 12 | .01274 | 33.5 | 29 | 4.73 | 3 |
| 112 | 12 | .02399 | 33.5 | 29 | 5.30 | 3 |
| 113 | 12 | .03705 | 33.5 | 29 | 6.50 | 4 |
| 114 | 12 | .05287 | 33.5 | 29 | 7.70 | 5 |
| 115 | 12 | .07146 | 33.5 | 29 | 8.82 | 7 |
| 116 | 12 | .09414 | 33.5 | 29 | 10.68 | 9 |
| 117 | 14 | .01303 | 34 | 29 | 5.50 | 3 |
| 118 | 14 | .02446 | 34 | 29 | 6.30 | 4 |
| 119 | 14 | .03769 | 34 | 29 | 6.70 | 6 |
| 120 | 14 | .05362 | 34 | 29 | 9.03 | 7 |
| 121 | 14 | .07315 | 34 | 29 | 10.00 | 8 |
| 122 | 14 | .09598 | 34 | 29 | 11.75 | 10 |
| 123 | 20 | .01358 | 35 | 29.5 | 7.88 | 4 |
| 124 | 20 | .02583 | 35 | 39.5 | 8.48 | 6 |
| 125 | 20 | .04012 | 35 | 29.5 | 9.60 | 7 |
| 126 | 20 | .05650 | 35 | 29.5 | 11.38 | 9 |
| 127 | 20 | .07636 | 35 | 29.5 | 13.88 | 12 |
| 128 | 20 | .09947 | 35 | 29.5 | 16.04 | 14 |
| 129 | 30 | .01512 | 35 | 30 | 11.00 | 9 |
| 130 | 30 | .02878 | 35 | 30 | 13.48 | 11 |
| 131 | 30 | .04405 | 35 | 30 | 15.05 | 13 |
| 132 | 30 | .06253 | 35 | 30 | 17.82 | 16 |
| 133 | 30 | .08392 | 35 | 30 | 19.65 | 20 |
| 134 | 30 | .09963 | 35 | 30 | 21.03 | 22 |
| 135 | 40 | .01654 | 35.5 | 30 | 16.24 | 13 |
| 136 | 40 | .03184 | 35.5 | 30 | 19.43 | 17 |
| 137 | 40 | .04965 | 35.5 | 30 | 22.10 | 21 |
| 138 | 40 | .06806 | 35.5 | 30 | 23.43 | 25 |

Table 4C

**Data for Co-Current Flow** of Air and Water in 1 1/2 Inch Test
Section 314 Inches Long With Globe Valve, Full Open, for Turbulator

| Run No. | $Q_L$ | $W_G$ | $T_L$ | $T_G$ | $(\Delta P)_{exp}$ | $P_1$ |
|---|---|---|---|---|---|---|
| | (GPM) | (lb/sec) | (°C) | (°C) | (in. Hg) | (psig) |
| 139 | 4 | | 32 | | 0 | 0 |
| 140 | 8 | | 32 | | .48 | 0 |
| 141 | 12 | | 32 | | .82 | 0 |
| 142 | 20 | | 32 | | 2.10 | 1 |
| 143 | 30 | | 32 | | 4.82 | 2 |
| 144 | 40 | | 32 | | 8.35 | 5 |
| 145 | 4 | .01208 | 32 | 32 | 1.20 | 0 |
| 146 | 4 | .02185 | 32 | 32 | 2.00 | 0 |
| 147 | 4 | .03350 | 32 | 32 | 2.78 | 0 |
| 148 | 4 | .04867 | 33 | 32 | 3.17 | 1 |
| 149 | 4 | .06486 | 33 | 32 | 3.75 | 1 |
| 150 | 4 | .08796 | 33 | 32 | 4.73 | 2 |
| 151 | 4 | .10587 | 33 | 32 | 5.12 | 3 |
| 152 | 8 | .01209 | 33 | 31 | 3.72 | 1 |
| 153 | 8 | .02341 | 33 | 31 | 3.95 | 2 |
| 154 | 8 | .03494 | 33 | 31 | 4.73 | 3 |
| 155 | 8 | .04956 | 33 | 31 | 5.50 | 4 |
| 156 | 8 | .06861 | 33 | 31 | 6.70 | 5 |
| 157 | 8 | .09383 | 33 | 31 | 7.70 | 6 |
| 158 | 12 | .01271 | 34 | 30.5 | 5.12 | 2 |
| 159 | 12 | .02392 | 34 | 30.5 | 6.10 | 3 |
| 160 | 12 | .03696 | 34 | 30.5 | 6.70 | 4 |
| 161 | 12 | .05197 | 34 | 30.5 | 7.10 | 6 |
| 162 | 12 | .07128 | 34 | 30.5 | 8.86 | 8 |
| 163 | 12 | .09574 | 34 | 30.5 | 10.80 | 9 |
| 164 | 20 | .01422 | 35 | 28 | 7.88 | 5 |
| 165 | 20 | .02589 | 35 | 28 | 9.62 | 6 |
| 166 | 20 | .04022 | 35 | 28 | 10.58 | 8 |
| 167 | 20 | .05735 | 35 | 28 | 12.93 | 10 |
| 168 | 20 | .07814 | 35 | 28 | 16.03 | 12 |
| 169 | 20 | .10059 | 35 | 28 | 16.63 | 15 |
| 170 | 30 | .01493 | 36 | 28 | 11.95 | 9 |
| 171 | 30 | .02888 | 36 | 28 | 15.05 | 12 |
| 172 | 30 | .04527 | 36 | 28 | 18.83 | 15 |
| 173 | 30 | .06337 | 36 | 28 | 19.83 | 18 |
| 174 | 30 | .08492 | 36 | 28 | 20.82 | 20 |
| 175 | 30 | .10815 | 36 | 28 | 22.62 | 23 |
| 176 | 40 | .01704 | 36 | 28 | 18.64 | 15 |

Table 40 (Concluded)

Data for Co-Current Flow of Air and Water in 1 1/2 Inch Test Section 314 Inches Long With Globe Valve, Full Open, for Turbulator

| Run No. | $Q_L$ (GPM) | $W_G$ (lb/sec) | $T_L$ (°C) | $T_G$ (°C) | $(\Delta P)_{exp}$ (in. Hg) | $P_1$ (psig) |
|---|---|---|---|---|---|---|
| 177 | 40 | .03231 | 36 | 28 | 20.23 | 18 |
| 178 | 40 | .04981 | 36 | 28 | 22.85 | 22 |
| 179 | 40 | .07004 | 36 | 28 | 26.60 | 27 |

Table 4D

Data for Co-Current Flow of Air and Water in 1 1/2 Inch Test Section 314 Inches Long with Globe Valve, Half Open, for Turbulator

| Run No. | $Q_L$ (GPM) | $W_G$ (lb/sec) | $T_L$ (°C) | $T_G$ (°C) | $(\Delta P)_{exp}$ (in. Hg) | $P_1$ (psig) |
|---|---|---|---|---|---|---|
| 180 | 4 | | 29.5 | | .02 | 0 |
| 181 | 8 | | 30 | | .42 | 0 |
| 182 | 12 | | 30 | | 1.02 | 0 |
| 183 | 20 | | 30 | | 2.85 | 1 |
| 184 | 30 | | 30 | | 6.81 | 4 |
| 185 | 40 | | 30 | | 12.51 | 6 |
| 186 | 4 | .01179 | 31 | 31 | 1.20 | 0 |
| 187 | 4 | .02188 | 31 | 31 | 1.80 | 0 |
| 188 | 4 | .03356 | 31 | 31 | 2.58 | 1 |
| 189 | 4 | .04792 | 31 | 31 | 3.95 | 1 |
| 190 | 4 | .06497 | 31 | 31 | 4.36 | 2 |
| 191 | 4 | .08810 | 31 | 31 | 5.30 | 3 |
| 192 | 4 | .10802 | 31 | 31 | 6.90 | 4 |
| 193 | 8 | .01211 | 31 | 30.5 | 4.16 | 1 |
| 194 | 8 | .02293 | 31 | 30.5 | 4.75 | 3 |
| 195 | 8 | .03565 | 31 | 30.5 | 5.32 | 4 |
| 196 | 8 | .05041 | 32 | 30.5 | 6.10 | 4 |
| 197 | 8 | .06867 | 32 | 30.5 | 6.90 | 5 |
| 198 | 8 | .09203 | 32 | 30.5 | 9.22 | 6 |
| 199 | 12 | .01297 | 32.5 | 31.5 | 5.90 | 3 |
| 200 | 12 | .02388 | 32.5 | 31.5 | 6.70 | 4 |
| 201 | 12 | .03754 | 32.5 | 31.5 | 7.86 | 5 |
| 202 | 12 | .05340 | 33 | 31.5 | 9.22 | 7 |
| 203 | 12 | .07201 | 33 | 31.5 | 10.40 | 8 |
| 204 | 12 | .09558 | 33 | 31.5 | 11.78 | 9 |
| 205 | 20 | .01407 | 33 | 31.5 | 9.80 | 6 |
| 206 | 20 | .02663 | 33 | 31.5 | 11.55 | 8 |
| 207 | 20 | .04057 | 33 | 31.5 | 12.72 | 9 |
| 208 | 20 | .05909 | 33 | 31.5 | 16.22 | 12 |
| 209 | 20 | .07847 | 33 | 31.5 | 18.25 | 15 |
| 210 | 20 | .09818 | 33 | 31.5 | 20.23 | 17 |
| 211 | 30 | .01557 | 34 | 31.5 | 15.85 | 11 |
| 212 | 30 | .02989 | 34 | 31.5 | 19.22 | 14 |
| 213 | 30 | .04605 | 34 | 31.5 | 22.25 | 17 |
| 214 | 30 | .06550 | 34 | 31.5 | 24.61 | 20 |
| 215 | 30 | .08514 | 34 | 31.5 | 25.24 | 22 |
| 216 | 30 | .1700 | 34 | 31.5 | 27.00 | 28 |
| 217 | 40 | .01736 | 35 | 32 | 23.06 | 18 |
| 218 | 40 | .03316 | 35 | 32 | 25.42 | 23 |
| 219 | 40 | .04948 | 35 | 32 | 26.80 | 25 |

Table 4E

Data for Co-Current Flow of Air and Water in 1 1/2 Inch Test Section 314 Inches Long With 3/4 Inch Orifice For Turbulator

| Run No. | $Q_L$ (GPM) | $W_G$ (lb/sec) | $T_L$ (°C) | $T_G$ (°C) | $(\Delta P)_{exp}$ (in. Hg) | $P_1$ (psig) |
|---|---|---|---|---|---|---|
| 220 | 4 | | 31 | | .15 | 0 |
| 221 | 8 | | 31 | | .85 | 0 |
| 222 | 12 | | 31 | | 1.92 | 1 |
| 223 | 20 | | 31 | | 5.95 | 3 |
| 224 | 30 | | 31 | | 13.48 | 7 |
| 225 | 40 | | 31 | | 24.21 | 13 |
| 226 | 4 | .01210 | 32 | 31 | 1.80 | 1 |
| 227 | 4 | .02240 | 33 | 31 | 3.00 | 1 |
| 228 | 4 | .03356 | 33 | 31 | 4.00 | 1 |
| 229 | 4 | .04792 | 33 | 31 | 4.75 | 2 |
| 230 | 4 | .06590 | 33 | 31 | 6.32 | 3 |
| 231 | 4 | .09020 | 33 | 30 | 8.25 | 4 |
| 232 | 8 | .01242 | 33.5 | 30 | 4.93 | 2 |
| 233 | 8 | .02394 | 33.5 | 30 | 5.31 | 2 |
| 234 | 8 | .03634 | 33.5 | 30 | 7.48 | 4 |
| 235 | 8 | .05045 | 33.5 | 30 | 8.45 | 5 |
| 236 | 8 | .07048 | 33.5 | 30 | 10.20 | 7 |
| 237 | 8 | .09305 | 33.5 | 30 | 12.90 | 9 |
| 238 | 12 | .01297 | 31 | 31.5 | 6.90 | 4 |
| 239 | 12 | .02483 | 31 | 31.5 | 8.06 | 6 |
| 240 | 12 | .03816 | 31 | 31.5 | 9.25 | 7 |
| 241 | 12 | .05340 | 31 | 31.5 | 11.55 | 8 |
| 242 | 12 | .07285 | 31 | 31.5 | 12.90 | 10 |
| 243 | 12 | .09566 | 31 | 31 | 15.62 | 14 |
| 244 | 20 | .01460 | 31 | 31 | 12.51 | 8 |
| 245 | 20 | .02750 | 31 | 31 | 14.08 | 10 |
| 246 | 20 | .04288 | 31 | 31 | 16.22 | 12 |
| 247 | 20 | .06113 | 31 | 31 | 20.05 | 15 |
| 248 | 20 | .08157 | 31 | 31 | 22.62 | 20 |
| 249 | 30 | .01676 | 31 | 30 | 21.62 | 15 |
| 250 | 30 | .03221 | 31 | 30 | 25.00 | 20 |
| 251 | 30 | .04868 | 31 | 30 | 26.60 | 24 |
| 252 | 40 | .01783 | 32 | 30 | 28.18 | 15 |

Table 4F

Data for Co-Current Flow of Air and Water in 1 1/2 Inch Test Section 314 Inches Long With 1 1/4 Inch Orifice for Turbulator

| Run No. | $Q_L$ (GPM) | $W_G$ (lb/sec) | $T_L$ (°C) | $T_G$ (°C) | $(\Delta P)_{exp}$ (in. Hg) | $P_1$ (psig) |
|---|---|---|---|---|---|---|
| 253 | 2 | | 30 | | 0 | 0 |
| 254 | 6 | | 30 | | .05 | 0 |
| 255 | 10 | | 30 | | .25 | 0 |
| 256 | 14 | | 30 | | .50 | 0 |
| 257 | 20 | | 31 | | 1.03 | 1 |
| 258 | 30 | | 31 | | 2.36 | 2 |
| 259 | 40 | | 31 | | 4.35 | 3 |
| 260 | 2 | .01180 | 31.5 | 30 | .25 | 0 |
| 261 | 2 | .02138 | 31.5 | 30 | 1.05 | 0 |
| 262 | 2 | .03290 | 32 | 30 | 1.20 | 0 |
| 263 | 2 | .04716 | 32 | 30 | 1.42 | 0 |
| 264 | 2 | .06413 | 32 | 30 | 1.80 | 0 |
| 265 | 2 | .08725 | 32 | 30 | 2.56 | 0 |
| 266 | 6 | .01213 | 32 | 29.5 | 2.56 | 0 |
| 267 | 6 | .02246 | 32 | 29.5 | 2.75 | 1 |
| 268 | 6 | .03434 | 32 | 29.5 | 3.38 | 1 |
| 269 | 6 | .06698 | 32 | 29.5 | 4.35 | 3 |
| 271 | 6 | .08930 | 32 | 29.5 | 5.52 | 4 |
| 272 | 10 | .01244 | 33 | 29 | 3.35 | 1 |
| 273 | 10 | .02349 | 33 | 29 | 3.94 | 2 |
| 274 | 10 | .03574 | 33 | 29 | 4.95 | 3 |
| 275 | 10 | .05132 | 33 | 29 | 5.50 | 5 |
| 276 | 10 | .06972 | 33 | 29 | 6.70 | 6 |
| 277 | 10 | .09226 | 33 | 29 | 7.50 | 8 |
| 278 | 14 | .01273 | 32.5 | 29 | 4.15 | 2 |
| 279 | 14 | .02398 | 32.5 | 29 | 5.30 | 3 |
| 280 | 14 | .03769 | 34 | 29 | 6.32 | 5 |
| 281 | 14 | .05287 | 34 | 29 | 7.70 | 7 |
| 282 | 14 | .07231 | 34 | 29 | 8.46 | 9 |
| 283 | 14 | .09506 | 34 | 29 | 10.40 | 10 |
| 284 | 20 | .01329 | 34.5 | 30 | 6.12 | 4 |
| 285 | 20 | .02581 | 34.5 | 30 | 7.70 | 5 |
| 286 | 20 | .03948 | 34.5 | 30 | 8.65 | 7 |
| 287 | 20 | .05574 | 34.5 | 30 | 10.00 | 9 |
| 288 | 20 | .07550 | 34.5 | 30 | 11.55 | 11 |
| 289 | 20 | .09673 | 34.5 | 30 | 12.72 | 14 |
| 290 | 30 | .01488 | 35 | 30 | 8.45 | 7 |

Table 4F (Concluded)

Data for Co-Current Flow of Air and Water in 1 1/2 Inch Test Section 314 Inches Long With 1 1/4 Inch Orifice for Turbulator

| Run No. | $Q_L$ | $W_G$ | $T_L$ | $T_G$ | $(\Delta P)_{exp}$ | $P_1$ |
|---|---|---|---|---|---|---|
| | (GPM) | (lb/sec) | (°C) | (°C) | (in./Hg) | (psig) |
| 291 | 30 | .02796 | 35 | 30 | 10.00 | 9 |
| 292 | 30 | .04351 | 35 | 30 | 11.55 | 11 |
| 293 | 30 | .06123 | 35.5 | 30 | 13.87 | 14 |
| 294 | 30 | .08245 | 35.5 | 30 | 16.25 | 17 |
| 295 | 40 | .01607 | 36 | 30.5 | 11.00 | 10 |
| 296 | 40 | .03071 | 36 | 30.5 | 12.90 | 13 |
| 297 | 40 | .04765 | 36 | 30.5 | 15.44 | 16 |
| 298 | 40 | .06621 | 36 | 30.5 | 18.45 | 19 |
| 299 | 40 | .08879 | 36 | 30.5 | 20.05 | 23 |

Table 4G

Data for Co-Current Flow of Air and Water in 1 1/2 Inch Test Section 314 Inches Long With Two Off Center 1 1/4 Inch Orifices Six Inches Apart for Turbulator

| Run No. | $Q_L$ (GPM) | $W_G$ (lb/sec) | $T_L$ (°C) | $T_G$ (°C) | $(\Delta P)_{exp}$ (in. Hg) | $P_1$ (psig) |
|---|---|---|---|---|---|---|
| 300 | 2 | | 32 | | 0 | 0 |
| 301 | 6 | | 32 | | .15 | 0 |
| 302 | 10 | | 32 | | .50 | 0 |
| 303 | 14 | | 32 | | .95 | 1 |
| 304 | 20 | | 32 | | 1.60 | 2 |
| 305 | 30 | | 32 | | 3.16 | 3 |
| 306 | 40 | | 32 | | 5.56 | 4 |
| 307 | 2 | .01174 | 32.5 | 33.5 | 2.00 | 0 |
| 308 | 2 | .02179 | 32.5 | 33.5 | 2.15 | 0 |
| 309 | 2 | .03271 | 32.5 | 33.5 | 2.15 | 0 |
| 310 | 2 | .04603 | 32.5 | 33.5 | 2.38 | 0 |
| 311 | 2 | .06184 | 32.5 | 33.5 | 2.38 | 0 |
| 312 | 2 | .08774 | 32.5 | 33.5 | 2.97 | 0 |
| 313 | 2 | .10085 | 32.5 | 33.5 | 3.56 | 0 |
| 314 | 6 | .01206 | 34 | 33 | 2.38 | 1 |
| 315 | 6 | .02181 | 34 | 33 | 2.95 | 1 |
| 316 | 6 | .03415 | 34 | 33 | 3.17 | 1 |
| 317 | 6 | .04859 | 34 | 33 | 3.95 | 2 |
| 318 | 6 | .06660 | 34 | 33 | 4.34 | 2 |
| 319 | 6 | .08879 | 34 | 33 | 5.50 | 3 |
| 320 | 6 | .10672 | 34 | 33 | 6.30 | 4 |
| 321 | 10 | .01237 | 35 | 32.5 | 3.34 | 1 |
| 322 | 10 | .02286 | 35 | 32.5 | 4.15 | 2 |
| 323 | 10 | .03486 | 35 | 32.5 | 4.55 | 3 |
| 324 | 10 | .04944 | 35 | 32.5 | 5.10 | 4 |
| 325 | 10 | .07091 | 35 | 32.5 | 6.10 | 5 |
| 326 | 10 | .09174 | 35 | 32.5 | 7.65 | 7 |
| 327 | 14 | .01265 | 36 | 33 | 4.35 | 2 |
| 328 | 14 | .02382 | 36 | 33 | 5.30 | 3 |
| 329 | 14 | .03681 | 36 | 33 | 6.30 | 5 |
| 330 | 14 | .05252 | 36 | 33 | 7.85 | 6 |
| 331 | 14 | .07183 | 36 | 33 | 9.62 | 7 |
| 332 | 14 | .09444 | 36 | 33 | 10.60 | 9 |
| 333 | 20 | .01350 | 36 | 33 | 6.30 | 4 |
| 334 | 20 | .02568 | 36 | 33 | 7.66 | 6 |
| 335 | 20 | .03929 | 36 | 33 | 9.23 | 7 |

Table 4G (Concluded)

Data for Co-Current Flow of Air and Water in 1 1/2 Inch Test Section 314 Inches Long With Two Off Center 1 1/4 Inch Orifices Six Inches Apart for Turbulator

| Run No. | $Q_L$ | $W_G$ | $T_L$ | $T_G$ | $(\Delta P)_{exp}$ | $P_1$ |
|---|---|---|---|---|---|---|
| | (GPM) | (lb/sec) | (°C) | (°C) | (in. Hg) | (psig) |
| 336 | 20 | .05688 | 36 | 33 | 11.75 | 9 |
| 337 | 20 | .07512 | 36 | 33 | 12.92 | 12 |
| 338 | 20 | .09254 | 36 | 33 | 14.63 | 14 |
| 339 | 30 | .01479 | 36 | 33.5 | 9.05 | 7 |
| 340 | 30 | .02821 | 36 | 33.5 | 11.36 | 10 |
| 341 | 30 | .04380 | 36 | 33.5 | 12.52 | 12 |
| 342 | 30 | .06153 | 36 | 33.5 | 16.05 | 14 |
| 343 | 30 | .08198 | 36 | 33.5 | 16.83 | 17 |
| 344 | 30 | .09354 | 36 | 33.5 | 18.62 | 20 |
| 345 | 40 | .01620 | 37 | 34 | 12.70 | 11 |
| 346 | 40 | .03127 | 37 | 34 | 14.63 | 15 |
| 347 | 40 | .04738 | 37 | 34 | 16.83 | 18 |
| 348 | 40 | .06762 | 37 | 34 | 19.42 | 22 |
| 349 | 40 | .08828 | 37 | 34 | 21.82 | 24 |
| 350 | 40 | .01177 | 37 | 34 | 23.23 | 28 |

Table 4H

Data for Co-Current Flow of Air and Water
in 1 1/2 Inch Test Section 314 Inches Long With
Flat Plate Covering Upper Half Pipe Diameter for Turbulator

| Run No. | $Q_L$ | $W_G$ | $T_L$ | $T_G$ | $(\Delta P)_{exp}$ | $P_1$ |
|---|---|---|---|---|---|---|
| | (GPM) | (lb/sec) | (°C) | (°C) | (in. Hg) | (psig) |
| 351 | 2 | | 31 | | 0 | 0 |
| 352 | 6 | | 31 | | .05 | 0 |
| 353 | 10 | | 31 | | .54 | 0 |
| 354 | 14 | | 31 | | .80 | 0 |
| 355 | 20 | | 31 | | 1.50 | 1 |
| 356 | 30 | | 31 | | 3.44 | 2 |
| 357 | 40 | | 31 | | 4.35 | 5 |
| 358 | 2 | .01171 | 32 | 35 | .45 | 0 |
| 359 | 2 | .02121 | 32 | 35 | 1.05 | 0 |
| 360 | 2 | .03263 | 32 | 35 | 1.80 | 0 |
| 361 | 2 | .04677 | 32 | 35 | 2.25 | 0 |
| 362 | 2 | .06455 | 32 | 35 | 2.55 | 0 |
| 363 | 2 | .08654 | 32 | 35 | 3.35 | 1 |
| 364 | 2 | .10935 | 32 | 35 | 4.15 | 2 |
| 365 | 6 | .01204 | 33 | 34 | 2.30 | 0 |
| 366 | 6 | .02177 | 33 | 34 | 2.96 | 1 |
| 367 | 6 | .03409 | 33 | 34 | 3.35 | 1 |
| 368 | 6 | .04851 | 33 | 34 | 3.95 | 1 |
| 369 | 6 | .06657 | 33 | 34 | 4.55 | 2 |
| 370 | 6 | .08969 | 33 | 34 | 5.50 | 4 |
| 371 | 10 | .01234 | 34 | 33.5 | 3.55 | 1 |
| 372 | 10 | .02332 | 34 | 33.5 | 4.35 | 2 |
| 373 | 10 | .03547 | 34 | 33.5 | 4.73 | 3 |
| 374 | 10 | .05016 | 34 | 33.5 | 5.50 | 4 |
| 375 | 10 | .06921 | 34 | 33.5 | 7.28 | 5 |
| 376 | 10 | .09253 | 34 | 33.5 | 8.25 | 7 |
| 377 | 14 | .01293 | 35 | 33.5 | 4.95 | 2 |
| 378 | 14 | .02380 | 35 | 33.5 | 5.50 | 3 |
| 379 | 14 | .03741 | 35 | 33.5 | 6.70 | 4 |
| 380 | 14 | .05323 | 35 | 33.5 | 8.05 | 6 |
| 381 | 14 | .07178 | 35 | 33.5 | 9.42 | 8 |
| 382 | 14 | .09527 | 35 | 33.5 | 10.80 | 9 |
| 383 | 20 | .01349 | 36 | 33.5 | 7.10 | 4 |
| 384 | 20 | .02566 | 36 | 33.5 | 8.05 | 6 |
| 385 | 20 | .03985 | 36 | 33.5 | 9.80 | 7 |
| 386 | 20 | .05683 | 36 | 33.5 | 11.15 | 9 |
| 387 | 20 | .07665 | 36 | 33.5 | 13.68 | 11 |

Table 4H (Concluded)

Data for Co-Current Flow of Air and Water
in 1 1/2 Inch Test Section 314 Inches Long With
Flat Plate Covering Upper Half Pipe Diameter for Turbulator

| Run No. | $Q_L$ | $W_G$ | $T_L$ | $T_G$ | $(\Delta P)_{exp}$ | $P_1$ |
|---|---|---|---|---|---|---|
| | (GPM) | (lb/sec) | (°C) | (°C) | (in. Hg) | (psig) |
| 388 | 20 | .09329 | 36 | 33.5 | 15.23 | 14 |
| 389 | 30 | .01479 | 37 | 33.5 | 9.80 | 8 |
| 390 | 30 | .02821 | 37 | 33.5 | 12.72 | 10 |
| 391 | 30 | .04326 | 37 | 33.5 | 14.24 | 12 |
| 392 | 30 | .06217 | 37 | 33.5 | 17.23 | 15 |
| 393 | 30 | .08272 | 37 | 33.5 | 19.43 | 18 |
| 394 | 40 | .01620 | 37 | 34 | 14.25 | 12 |
| 395 | 40 | .03163 | 37 | 34 | 17.45 | 16 |
| 396 | 40 | .04787 | 37 | 34 | 19.45 | 18 |
| 397 | 40 | .06762 | 37 | 34 | 22.25 | 22 |
| 398 | 40 | .08974 | 37 | 34 | 23.82 | 28 |
| 399 | -- | ------ | No Run | Made | ----- | -- |

Table 4I

Data for Co-Current Flow of Air and
Water in 1 1/2 Inch Test Section 314 Inches Long
With Flat Plate Covering Upper Two-Thirds Pipe Diameter for Turbulator

| Run No. | $Q_L$ | $W_G$ | $T_L$ | $T_G$ | $(\Delta P)_{exp}$ | $P_1$ |
|---|---|---|---|---|---|---|
| | (GPM) | (lb/sec) | (°C) | (°C) | (in. Hg) | (psig) |
| 400 | 2 | | 35 | | 2.35 | 1 |
| 401 | 6 | | 35 | | 3.17 | 2 |
| 402 | 10 | | 35 | | 4.94 | 3 |
| 403 | 14 | | 35 | | 7.28 | 4 |
| 404 | 20 | | 35 | | 12.32 | 7 |
| 405 | 30 | | 35 | | 28.00 | 15 |
| 406 | 2 | .01182 | 36 | 29 | 2.35 | 1 |
| 407 | 2 | .02142 | 36 | 29 | 3.17 | 1 |
| 408 | 2 | .03295 | 36 | 29 | 3.75 | 2 |
| 409 | 2 | .04808 | 36 | 29 | 5.50 | 2 |
| 410 | 2 | .06612 | 36 | 29 | 7.50 | 3 |
| 411 | 2 | .08938 | 36 | 29 | 10.00 | 4 |
| 412 | 2 | .10742 | 36 | 29 | 12.92 | 6 |
| 413 | 6 | .01210 | 37 | 31 | 5.33 | 2 |
| 414 | 6 | .02390 | 37 | 31 | 6.30 | 3 |
| 415 | 6 | .03562 | 37 | 31 | 8.06 | 5 |
| 416 | 6 | .04956 | 37 | 31 | 10.21 | 6 |
| 417 | 6 | .06957 | 37 | 31 | 13.08 | 8 |
| 418 | 6 | .09290 | 37 | 31 | 16.05 | 9 |
| 419 | 10 | .01296 | 37.5 | 32 | 9.82 | 6 |
| 420 | 10 | .02434 | 37.5 | 32 | 11.18 | 7 |
| 421 | 10 | .03875 | 37.5 | 32 | 11.54 | 8 |
| 422 | 10 | .05410 | 37.5 | 32 | 14.64 | 10 |
| 423 | 10 | .07525 | 37.5 | 32 | 19.05 | 14 |
| 424 | 10 | .09906 | 37.5 | 32 | 23.22 | 19 |
| 425 | 14 | .01404 | 38 | 33 | 13.08 | 9 |
| 426 | 14 | .02656 | 38 | 33 | 14.65 | 11 |
| 427 | 14 | .04612 | 38 | 33 | 17.60 | 13 |
| 428 | 14 | .05826 | 38 | 33 | 20.83 | 16 |
| 429 | 14 | .07904 | 38 | 33 | 24.42 | 21 |
| 430 | 14 | .09149 | 38 | 33 | 26.03 | 23 |
| 431 | 20 | .01577 | 38 | 33 | 22.22 | 13 |
| 432 | 20 | .03095 | 38 | 33 | 24.05 | 19 |
| 433 | 20 | .04459 | 38 | 33 | 26.05 | 23 |
| 434 | 20 | .06349 | 38 | 33 | 26.80 | 26 |

Table 4J

Data for Co-Current Flow of Air and Water in 1 1/2 Inch
Test Section 314 Inches Long With Segmented Orifice for Turbulator

| Run No. | $Q_L$ (GPM) | $W_G$ (lb/sec) | $T_L$ (°C) | $T_G$ (°C) | $(\Delta P)_{exp}$ (in. Hg) | $P_1$ (psig) |
|---|---|---|---|---|---|---|
| 435 | 2 | | 31 | | .05 | 0 |
| 436 | 6 | | 31 | | .47 | 0 |
| 437 | 10 | | 31 | | .75 | 0 |
| 438 | 14 | | 31 | | 1.10 | 1 |
| 439 | 20 | | 31 | | 1.90 | 1 |
| 440 | 30 | | 31 | | 3.38 | 2 |
| 441 | 40 | | 31 | | 5.50 | 2 |
| 442 | 2 | .01178 | 32 | 31.5 | 1.60 | 0 |
| 443 | 2 | .02133 | 32 | 31.5 | 2.20 | 0 |
| 444 | 2 | .03282 | 32 | 31.5 | 2.28 | 0 |
| 445 | 2 | .04618 | 32 | 31.5 | 2.35 | 0 |
| 446 | 2 | .06492 | 32 | 31.5 | 2.78 | 0 |
| 447 | 2 | .08704 | 32 | 31.5 | 3.36 | 0 |
| 448 | 2 | .10596 | 32 | 31.5 | 4.14 | 1 |
| 449 | 6 | .01212 | 33 | 30 | 2.98 | 1 |
| 450 | 6 | .02244 | 33 | 30 | 3.38 | 1 |
| 451 | 6 | .03361 | 33 | 30 | 3.75 | 1 |
| 452 | 6 | .04883 | 33 | 30 | 3.95 | 2 |
| 453 | 6 | .06600 | 33 | 30 | 4.74 | 3 |
| 453 | 6 | .06600 | 33 | 30 | 4.74 | 3 |
| 454 | 6 | .08923 | 33 | 30 | 5.50 | 4 |
| 455 | 6 | .10244 | 33 | 30 | 6.10 | 4 |
| 456 | 10 | .01242 | 34 | 30 | 4.14 | 1 |
| 457 | 10 | .02345 | 34 | 30 | 4.14 | 2 |
| 458 | 10 | .03640 | 34 | 30 | 5.50 | 3 |
| 459 | 10 | .05124 | 34 | 30 | 5.72 | 4 |
| 460 | 10 | .06961 | 34 | 30 | 6.50 | 5 |
| 461 | 10 | .09211 | 34 | 30 | 8.85 | 7 |
| 462 | 14 | .01271 | 34.5 | 30.5 | 5.10 | 3 |
| 463 | 14 | .02392 | 34.5 | 30.5 | 6.10 | 3 |
| 464 | 14 | .03696 | 34.5 | 30.5 | 6.30 | 5 |
| 465 | 14 | .05274 | 34.5 | 30.5 | 7.63 | 7 |
| 466 | 14 | .07297 | 34.5 | 30.5 | 9.04 | 8 |
| 467 | 14 | .09482 | 34.5 | 30.5 | 10.40 | 10 |
| 468 | 20 | .01357 | 35 | 30 | 6.10 | 5 |
| 469 | 20 | .02581 | 35 | 30 | 8.05 | 6 |
| 470 | 20 | .04008 | 35 | 30 | 9.82 | 7 |
| 471 | 20 | .05716 | 35 | 30 | 11.96 | 10 |

Table 4J (Concluded)

Data for Co-Current Flow of Air and Water in 1 1/2 Inch
Test Section 314 Inches Long With Segmented Orifice for Turbulator

| Run No. | $Q_L$ (GPM) | $W_G$ (lb/sec) | $T_L$ (°C) | $T_G$ (°C) | $(\Delta P)_{exp}$ (in. Hg) | $P_1$ (psig) |
|---|---|---|---|---|---|---|
| 472 | 20 | .07550 | 35 | 30 | 12.72 | 12 |
| 473 | 20 | .10026 | 35 | 30 | 14.63 | 16 |
| 474 | 20 | .11974 | 35 | 30 | 16.04 | 18 |
| 475 | 30 | .01485 | 35.5 | 31 | 9.62 | 7 |
| 476 | 30 | .02833 | 35.5 | 31 | 11.75 | 9 |
| 477 | 30 | .04398 | 35.5 | 31 | 13.68 | 13 |
| 478 | 30 | .06178 | 35.5 | 31 | 16.63 | 16 |
| 479 | 30 | .08231 | 35.5 | 31 | 17.64 | 18 |
| 480 | 40 | .01654 | 36 | 30 | 13.48 | 12 |
| 481 | 40 | .03073 | 36 | 30 | 15.85 | 15 |
| 482 | 40 | .04818 | 36 | 30 | 18.24 | 18 |
| 483 | 40 | .06747 | 36 | 30 | 21.23 | 22 |
| 484 | 40 | .08886 | 36 | 30 | 22.42 | 26 |

Table 4K

Data for Co-Current Flow of Air and Water in
1 1/2 Inch Test Section 314 Inches Long With Spiral Coil for Turbulator

| Run No. | $Q_L$ (GPM) | $W_G$ (lb/sec) | $T_L$ (°C) | $T_G$ (°C) | $(\Delta P)_{exp}$ (in. Hg) | $P_1$ (psig) |
|---|---|---|---|---|---|---|
| 485 | 2 | | 32 | | .10 | 0 |
| 486 | 6 | | 32 | | .30 | 0 |
| 487 | 10 | | 32 | | .49 | 0 |
| 488 | 14 | | 32 | | .73 | 0 |
| 489 | 20 | | 32 | | 1.22 | 0 |
| 490 | 30 | | 32 | | 2.56 | 2 |
| 491 | 40 | | 32 | | 4.23 | 3 |
| 492 | 2 | .01183 | 33 | 28.5 | .65 | 0 |
| 493 | 2 | .02143 | 33 | 28.5 | 1.40 | 0 |
| 494 | 2 | .03298 | 33 | 28.5 | 1.02 | 0 |
| 495 | 2 | .04641 | 33 | 28.5 | 1.60 | 0 |
| 496 | 2 | .06429 | 33 | 28.5 | 2.00 | 0 |
| 497 | 2 | .08847 | 33 | 28.5 | 2.76 | 1 |
| 498 | 2 | .10852 | 33 | 28.5 | 3.75 | 2 |
| 499 | 6 | .01216 | 33.5 | 28.0 | 2.56 | 1 |
| 500 | 6 | .02199 | 33.5 | 28.0 | 2.95 | 1 |
| 501 | 6 | .03443 | 33.5 | 28.0 | 3.36 | 1 |
| 502 | 6 | .04899 | 33.5 | 28.0 | 3.75 | 2 |
| 503 | 6 | .06715 | 33.5 | 28.0 | 4.34 | 3 |
| 504 | 6 | .08952 | 33.5 | 28.0 | 5.50 | 4 |
| 505 | 6 | .11726 | 33.5 | 28.0 | 6.90 | 4 |
| 506 | 10 | .01246 | 33.5 | 28.0 | 3.55 | 1 |
| 507 | 10 | .02303 | 33.5 | 28.0 | 4.34 | 2 |
| 508 | 10 | .03580 | 33.5 | 28.0 | 4.95 | 3 |
| 509 | 10 | .05141 | 33.5 | 28.0 | 5.50 | 4 |
| 510 | 10 | .06984 | 33.5 | 28.0 | 6.12 | 4 |
| 511 | 10 | .09242 | 33.5 | 28.0 | 7.28 | 6 |
| 512 | 14 | .01276 | 34 | 28.0 | 3.95 | 3 |
| 513 | 14 | .02450 | 34 | 28.0 | 5.92 | 3 |
| 514 | 14 | .03775 | 34 | 28.0 | 6.50 | 4 |
| 515 | 14 | .05296 | 34 | 28.0 | 7.08 | 6 |
| 516 | 14 | .07158 | 34 | 28.0 | 8.85 | 7 |
| 517 | 14 | .09522 | 34 | 28.0 | 10.77 | 8 |
| 518 | 20 | .01359 | 34 | 29.0 | 5.90 | 3 |
| 519 | 20 | .02493 | 34 | 29.0 | 6.70 | 5 |
| 520 | 20 | .03954 | 34 | 39.0 | 8.45 | 7 |
| 521 | 20 | .05583 | 34 | 29.0 | 9.82 | 9 |
| 522 | 20 | .07643 | 34 | 29.0 | 12.90 | 12 |

Table 4K (Concluded)

Data for Co-Current Flow of Air and Water in
1 1/2 Inch Test Section 314 Inches Long With Spiral Coil for Turbulator

| Run No. | $Q_L$ (GPM) | $W_G$ (lb/sec) | $T_L$ (°C) | $T_G$ (°C) | $(\Delta P)_{exp}$ (in. Hg) | $P_1$ (psig) |
|---|---|---|---|---|---|---|
| 523 | 20 | .09398 | 34 | 29.0 | 13.30 | 13 |
| 524 | 30 | .01647 | 35 | 28.0 | 7.30 | 7 |
| 525 | 30 | .02764 | 35 | 28.0 | 8.05 | 9 |
| 526 | 30 | .04365 | 35 | 28.0 | 12.50 | 12 |
| 527 | 30 | .06143 | 35 | 28.0 | 14.08 | 14 |
| 528 | 30 | .08346 | 35 | 28.0 | 15.43 | 17 |
| 529 | 30 | .09263 | 35 | 28.0 | 17.45 | 19 |
| 530 | 40 | .01613 | 35 | 28.0 | 11.18 | 11 |
| 531 | 40 | .03045 | 35 | 28.0 | 12.70 | 13 |
| 532 | 40 | .04785 | 35 | 28.0 | 15.05 | 16 |
| 533 | 40 | .06710 | 35 | 28.0 | 18.23 | 20 |
| 534 | 40 | .08777 | 35 | 28.0 | 19.65 | 23 |
| 535 | 40 | .11673 | 35 | 28.0 | 23.42 | 28 |

Table 4L

Data for Co-Current Flow of Air and Water in 1 1/2 Inch Test Section 314 Inches Long With Propeller for Turbulator

| Run No. | $Q_L$ (GPM) | $W_G$ (lb/sec) | $T_L$ (°C) | $T_G$ (°C) | $(\Delta P)_{exp}$ (in. Hg) | $P_1$ (psig) |
|---|---|---|---|---|---|---|
| 536 | 2 | | 35 | | 0 | 0 |
| 537 | 6 | | 35 | | .13 | 0 |
| 538 | 10 | | 35 | | .50 | 0 |
| 539 | 14 | | 35 | | .82 | 0 |
| 540 | 20 | | 35 | | 1.90 | 1 |
| 541 | 30 | | 35 | | 3.95 | 3 |
| 542 | 40 | | 35 | | 6.90 | 5 |
| 543 | 2 | .01180 | 35 | 30.0 | .65 | 0 |
| 544 | 2 | .02192 | 35 | 30.0 | 1.40 | 0 |
| 545 | 2 | .03290 | 35 | 30.0 | 1.80 | 0 |
| 546 | 2 | .04716 | 35 | 30.0 | 2.38 | 0 |
| 547 | 2 | .06508 | 35 | 30.0 | 2.78 | 0 |
| 548 | 2 | .08625 | 35 | 30.0 | 3.36 | 1 |
| 549 | 2 | .11124 | 35 | 30.0 | 4.94 | 3 |
| 550 | 6 | .01212 | 34 | 30.0 | 3.16 | 0 |
| 551 | 6 | .02244 | 34 | 30.0 | 3.55 | 1 |
| 552 | 6 | .03432 | 34 | 30.0 | 3.55 | 1 |
| 553 | 6 | .04800 | 34 | 30.0 | 4.15 | 2 |
| 554 | 6 | .06693 | 34 | 30.0 | 5.32 | 3 |
| 555 | 6 | .08923 | 34 | 30.0 | 6.38 | 4 |
| 556 | 10 | .01243 | 34.5 | 29.5 | 4.35 | 2 |
| 557 | 10 | .02297 | 34.5 | 29.5 | 5.10 | 3 |
| 558 | 10 | .03571 | 34.5 | 29.5 | 5.32 | 4 |
| 559 | 10 | .05128 | 34.5 | 29.5 | 6.10 | 6 |
| 560 | 10 | .06967 | 34.5 | 29.5 | 8.45 | 6 |
| 561 | 10 | .09313 | 34.5 | 29.5 | 9.61 | 8 |
| 562 | 14 | .01273 | 35 | 29.5 | 5.32 | 3 |
| 563 | 14 | .02396 | 35 | 29.5 | 7.08 | 4 |
| 564 | 14 | .03766 | 35 | 29.5 | 7.88 | 6 |
| 565 | 14 | .05358 | 35 | 29.5 | 8.85 | 7 |

Table 4M

Data for Co-Current Flow of Air and Water in 1 1/2 Inch Test Section 314 Inches Long With Packed Section for Turbulator

| Run No. | $Q_L$ | $W_G$ | $T_L$ | $T_G$ | $(\Delta P)_{exp}$ | $P_1$ |
|---|---|---|---|---|---|---|
| | (GPM) | (lb/sec) | (°C) | (°C) | (in. Hg) | (psig) |
| 566 | 2 | | 30.5 | | .10 | 0 |
| 567 | 6 | | 30.5 | | 1.00 | 0 |
| 568 | 10 | | 30.5 | | 3.05 | 3 |
| 569 | 14 | | 30.5 | | 5.55 | 4 |
| 570 | 20 | | 30.5 | | 11.75 | 7 |
| 571 | 30 | | 30.5 | | 27.00 | 15 |
| 572 | 2 | .01176 | 31 | 32.0 | 1.42 | 0 |
| 573 | 2 | .02184 | 31 | 32.0 | 3.15 | 0 |
| 574 | 2 | .03420 | 31 | 32.0 | 4.14 | 1 |
| 575 | 2 | .04784 | 31 | 32.0 | 5.12 | 2 |
| 576 | 2 | .06579 | 31 | 32.0 | 7.28 | 3 |
| 577 | 2 | .08990 | 31 | 32.0 | 10.20 | 5 |
| 578 | 6 | .01240 | 32 | 31.0 | 5.12 | 2 |
| 579 | 6 | .02341 | 32 | 31.0 | 6.12 | 3 |
| 580 | 6 | .03495 | 32 | 31.0 | 8.65 | 4 |
| 581 | 6 | .05036 | 32 | 31.0 | 10.20 | 5 |
| 582 | 6 | .06949 | 32 | 31.0 | 13.67 | 7 |
| 583 | 6 | .09383 | 32 | 31.0 | 17.63 | 10 |
| 584 | 10 | .01354 | 33 | 31.0 | 9.80 | 5 |
| 585 | 10 | .02571 | 33 | 31.0 | 12.13 | 7 |
| 586 | 10 | .03942 | 33 | 31.0 | 15.05 | 10 |
| 587 | 10 | .05565 | 33 | 31.0 | 17.45 | 11 |
| 588 | 10 | .07617 | 33 | 31.0 | 21.25 | 16 |
| 589 | 10 | .10010 | 33 | 31.0 | 24.00 | 19 |
| 590 | 14 | .01434 | 34 | 31.0 | 15.43 | 9 |
| 591 | 14 | .02792 | 34 | 31.0 | 16.83 | 12 |
| 592 | 14 | .04233 | 34 | 31.0 | 19.83 | 13 |
| 593 | 14 | .05981 | 34 | 31.0 | 23.05 | 17 |
| 594 | 14 | .08082 | 34 | 31.0 | 27.20 | 21 |
| 595 | 20 | .01604 | 34 | 31.5 | 23.60 | 14 |
| 596 | 20 | .03066 | 34 | 31.5 | 25.80 | 18 |

Table 4N

Data for Co-Current Flow of Air and Water in 1 1/2 Inch Test Section 314 Inches Long With No Turbulator

| Run No. | $Q_L$ (GPM) | $W_G$ (lb/sec) | $T_L$ (°C) | $T_G$ (°C) | $(\Delta P)_{exp}$ (in. Hg) | $P_1$ (psig) |
|---|---|---|---|---|---|---|
| 597 | 2 | | 30.5 | | .05 | 0 |
| 598 | 6 | | 30.5 | | .08 | 0 |
| 599 | 10 | | 30.5 | | .10 | 0 |
| 600 | 14 | | 30.5 | | .50 | 0 |
| 601 | 20 | | 30.5 | | .72 | 1 |
| 602 | 30 | | 30.5 | | 1.62 | 2 |
| 603 | 40 | | 30.5 | | 2.78 | 3 |
| 604 | 2 | .01147 | 31.5 | 31.0 | .63 | 0 |
| 605 | 2 | .02135 | 31.5 | 31.0 | 1.02 | 0 |
| 606 | 2 | .03211 | 31.5 | 31.0 | 1.60 | 0 |
| 607 | 2 | .04622 | 31.5 | 31.0 | 2.00 | 0 |
| 608 | 2 | .06403 | 31.5 | 31.0 | 3.26 | 0 |
| 609 | 2 | .08711 | 31.5 | 31.0 | 2.58 | 1 |
| 610 | 2 | .11366 | 31.5 | 31.0 | 3.35 | 2 |
| 611 | 6 | .01211 | 32.5 | 30.5 | 2.15 | 1 |
| 612 | 6 | .02242 | 32.5 | 30.5 | 3.15 | 2 |
| 613 | 6 | .03429 | 32.5 | 30.5 | 3.55 | 3 |
| 614 | 6 | .04796 | 32.5 | 30.5 | 3.55 | 3 |
| 615 | 6 | .06687 | 32.5 | 30.5 | 3.95 | 4 |
| 616 | 6 | .08916 | 32.5 | 30.5 | 4.72 | 4 |
| 617 | 6 | .10613 | 32.5 | 30.5 | 5.10 | 5 |
| 618 | 10 | .01241 | 33.5 | 30.5 | 3.15 | 1 |
| 619 | 10 | .02293 | 33.5 | 30.5 | 3.94 | 2 |
| 620 | 10 | .03564 | 33.5 | 30.5 | 4.35 | 3 |
| 621 | 10 | .05040 | 33.5 | 30.5 | 5.32 | 4 |
| 622 | 10 | .06867 | 33.5 | 30.5 | 6.10 | 6 |
| 623 | 10 | .09204 | 33.5 | 30.5 | 7.50 | 8 |
| 624 | 10 | .10133 | 33.5 | 30.5 | 7.85 | 8 |
| 625 | 14 | .01271 | 34 | 30.5 | 3.96 | 2 |
| 626 | 14 | .02440 | 34 | 30.5 | 5.50 | 3 |
| 627 | 14 | .03696 | 34 | 30.5 | 6.10 | 4 |
| 628 | 14 | .05197 | 34 | 30.5 | 7.07 | 6 |
| 629 | 14 | .07042 | 34 | 30.5 | 7.86 | 7 |
| 630 | 14 | .09298 | 34 | 30.5 | 8.83 | 8 |
| 631 | 20 | .01326 | 34 | 31.0 | 5.31 | 4 |
| 632 | 20 | .02485 | 34 | 31.0 | 6.10 | 5 |
| 633 | 20 | .03881 | 34 | 31.0 | 6.50 | 6 |
| 634 | 20 | .05419 | 34 | 31.0 | 8.64 | 7 |

Table 4N (Concluded)

Data for Co-Current Flow of Air and Water in 1 1/2 Inch Test Section 314 Inches Long With No Turbulator

| Run No. | $Q_L$ (GPM) | $W_G$ (lb/sec) | $T_L$ (°C) | $T_G$ (°C) | $(\Delta P)_{exp}$ (in. Hg) | $P_1$ (psig) |
|---|---|---|---|---|---|---|
| 635 | 20 | .07374 | 34 | 31.0 | 9.80 | 9 |
| 636 | 20 | .09656 | 34 | 31.0 | 10.98 | 12 |
| 637 | 30 | .01434 | 35.5 | 31.0 | 6.50 | 6 |
| 638 | 30 | .02750 | 35.5 | 31.0 | 8.06 | 8 |
| 639 | 30 | .04233 | 35.5 | 31.0 | 9.81 | 10 |
| 640 | 30 | .05928 | 35.5 | 31.0 | 11.73 | 13 |
| 641 | 30 | .08007 | 35.5 | 31.0 | 12.92 | 15 |
| 642 | 30 | .10434 | 35.5 | 31.0 | 14.44 | 17 |
| 643 | 40 | .01579 | 35.5 | 32.0 | 8.85 | 10 |
| 644 | 40 | .02987 | 35.5 | 32.0 | 10.40 | 12 |
| 645 | 40 | .04549 | 35.5 | 32.0 | 11.35 | 14 |
| 646 | 40 | .06544 | 35.5 | 32.0 | 15.64 | 18 |
| 647 | 40 | .08719 | 35.5 | 32.0 | 16.83 | 22 |

# APPENDIX II

## METHOD OF CALCULATION

The calculations of pressure drops, equivalent lengths, and other quantitites presented in Tables 1, 2, and 3 were made with aid of the IBM 650 computer of the Rich Electronic Computer Center of the Georgia Institute of Technology. In order to simplify the programming of the calculations the Bell General Purpose System was used. The programs used in making these calculations are on file in the School of Chemical Engineering of the Georgia Institute of Technology.

Three separate programs were set up for making the required calculations. The first program was used to determine the equivalent lengths of various turbulators used in different test runs. The purpose of the second program was to determine the values of $X^2$ and $\phi^2_{LTT}$ in two-phase flow with no turbulator present in the test section. The third of the these programs was used to calculate the pressure drops encountered in two-phase flow with turbulators in the test section and to check the correlation of Gossage (3) presented in Figure 15. The constants, conversion factors, and dimensions of the particular experimental apparatus used were included as part of the basic program.

Program One.--In the first program the input data to the computer consisted of the following variables for each test run made:

Run number

| | |
|---|---|
| $Q_L$ | GPM |
| $\mu_L$ | lb. mass/ft. sec. |
| $\rho_L$ | lb. mass/ft.$^3$ |
| $\Delta P_{exp}$ | in. Hg |

The calculations indicated in the following equations were made by the computer.

$$W_L = Q_L \cdot \left(\frac{1}{7.481}\right) \cdot \rho_L \cdot \frac{1}{60} \tag{1}$$

$$Re_L = \frac{4W_L}{\pi D \mu_L} \tag{2}$$

$$u_L = \frac{Q_L}{60 \cdot (7.481) \cdot A} \tag{3}$$

$$f_L^{-\frac{1}{2}} = -2 \log_{10} \left[\frac{\epsilon}{3.7D} + \frac{2.51}{Re_L \sqrt{f_L}}\right] \tag{4}$$

$$\left(\frac{\Delta P}{\Delta \ell}\right)_L = \frac{f_L \cdot u_L^2 \cdot \rho_L}{2g_c \cdot D \cdot (144)} \tag{5}$$

$$\left(\frac{\ell}{D}\right)_T = \frac{\dfrac{.4903\ \Delta P_{exp}}{\left(\frac{\Delta P}{\Delta \ell}\right)_L} - \ell_\rho}{D} \tag{6}$$

The computer punched out the values of $\left(\frac{\Delta P}{\Delta \ell}\right)_L$ and $\left(\frac{\ell}{D}\right)_T$ for each test run on standard IBM cards; these values are included in Table 1.

Program Two.--In addition to the variables used in the calculations of Program One, the following input data were required for the calculations involved in the two-phase test runs:

| | |
|---|---|
| $Q_G$ | CFM |
| $\mu_G$ | lb. mass/ft. sec. |
| $T_G$ | °C |
| $P_G$ | psig |
| $P_1$ | psig |

The computer performed the operations indicated by the following equations:

same as for Program One (1) - (5)

$$W_G = \frac{Q_G}{60}\left[\frac{20(P_G + 14.7)}{T_G + 273}\right]^{\frac{1}{2}} \rho_G \tag{7}$$

$$Re_G = \frac{4W_G}{\pi D\mu_G} \tag{8}$$

$$P_{avg} = (P_1 + 14.7) - \frac{1}{2}(.4903)\,\Delta P_{exp} \tag{9}$$

$$u_G = \frac{Q_G}{60A}\left[\frac{T_G + 273}{20(P_G + 14.7)}\right]^{\frac{1}{2}} \frac{(P_G + 14.7)}{P_{avg}} \tag{10}$$

$$f_G^{-\frac{1}{2}} = -2 \log_{10} \left[\frac{\epsilon}{3.7D} + \frac{2.51}{Reg \sqrt{f_G}}\right] \tag{11}$$

$$\left(\frac{\Delta P}{\Delta \ell}\right)_G = \frac{f_G \; u_G^2 \cdot (1.5)(P_{avg})}{2g_c \cdot D \cdot 144T_G} \tag{12}$$

$$X^2 = \left(\frac{\Delta P}{\Delta \ell}\right)_L \Big| \left(\frac{\Delta P}{\Delta \ell}\right)_G \tag{13}$$

$$\phi_{LTT}^2 = \frac{.4903\Delta \; P_{exp}}{\ell_p \cdot \left(\frac{\Delta P}{\Delta \ell}\right)_L} \tag{14}$$

The following quantities were punched out on IBM cards by the computer:

$\left(\frac{\Delta P}{\Delta \ell}\right)_L$

$W_G$

$\left(\frac{\Delta P}{\Delta \ell}\right)_G$

$X^2$

$\phi_{LTT}^2$

$\frac{W_L}{W_G}$

Some of these quantities are recorded in Table 2.

Program Three.--In addition to the variables used in the calculations of Program Two, the appropriate value of $\left(\frac{\ell}{D}\right)_T$ as determined in Program One for each turbulator was required in Program Three. Program Three consisted of the operations indicated by the following equations:

same as for Program Two (1) - (5) and (7) - (13)

$$\phi^2_{LTT} = 16.64\ (X^2)^{-0.444} \tag{15}$$

$$\left(\frac{\Delta P}{\Delta \ell}\right)_{T-P} = \phi^2_{LTT} \cdot \left(\frac{\Delta P}{\Delta \ell}\right)_L \tag{16}$$

$$\psi = \frac{\dfrac{.4903\Delta\ P_{exp}}{\left(\frac{\Delta P}{\Delta \ell}\right)_{T-P}} - \left(\frac{\ell}{D}\right)_P \cdot D}{\left(\frac{\ell}{D}\right)_T \cdot D} \tag{17}$$

The following quantities were punched out by the computer:

$\left(\frac{\Delta P}{\Delta \ell}\right)_L$

$W_G$

$\left(\frac{\Delta P}{\Delta \ell}\right)_G$

$X_2$

$\phi^2_{LTT}$

$$\frac{W_L}{W_G}$$

$$\left(\frac{\Delta P}{\Delta \ell}\right)_{T-P}$$

$$\psi$$

The values of some of these quantities are given in Table 3.

## BIBLIOGRAPHY


1. Lockhart, R. W., and R. C. Martinelli, "Proposed Correlation of Data for Isothermal Two-Phase Two-Component Flow in Pipes," Chemical Engineering Progress 45, No. 1, 39-48 (1949).

2. Sharp, Robert McKinlock, Two-Phase Pressure Losses in Valves and Fittings, Unpublished Master's Thesis, Georgia Institute of Technology, 1956.

3. Gossage, Tommy Layton, Two-Phase Pressure Losses in Valves, Unpublished Master's Thesis, Georgia Institute of Technology, 1957.

4. Baker, Ovid, "Design of Pipelines for Simultaneous Flow of Oil and Gas," American Insitute of Mining and Metallurgical Engineers, Preprint of Paper No. 323-6, Dallas, Texas, 1953.

5. Bergelin, Olaf P., "Flow of Gas-Liquid Mixtures," Chemical Engineering 56, 104-6 (1949).

6. Bergelin, Olaf P., and C. Grazley, "Co-Current Gas-Liquid Flow. I. Flow in Vertical Tubes," American Society of Mechanical Engineers, Preprint of Paper, May 1949, pp. 5-18.

7. Bergelin, Olaf P., and P. K. Kegel, "Co-Current Gas-Liquid Flow. II. Flow in Vertical Tubes," American Society of Mechanical Engineers, Preprint of Paper, May 1949, pp. 19-28.

8. Boelter, L. M. K., and Robert E. Kepner, "Pressure Drop Accompanying Two-Component Flow Through Pipes," Industrial Engineering Chemistry 31, 426-34 (1939).

9. Gazely, C., Jr., "Co-Current Gas-Liquid Flow. III. Interfacial Shear and Stability," American Society of Mechanical Engineers, Proceedings of the Heat Transfer and Fluid Mechanics Institute, June 22-24, 1949, pp. 29-40.

10. Huntington, R. L., "Two-Phase Flow in Pipelines," Minutes of a lecture delivered at Ethyl Corporation by the author, University of Oklahoma, May 10, 1954.

11. Gresham, William A., Jr., Perry A. Foster, Jr., and Robert J. Kyle, Review of the Literature on Two-Phase (Gas-Liquid) Fluid Flow in Pipes, Interim Report No. 1, Contract No. AF 33(616)-2660, Wright Air Development Center, Dayton, Ohio, June 30, 1955.

BIBLIOGRAPHY (Concluded)

12. Isben, H. S., R. E. Moen, and D. R. Mosher, Two-Phase Pressure Drops, AECU-2994, Department of Chemical Engineering, University of Minnesota, Minneapolis, Minnesota, November 1954.

13. Ward, Henderson C., Mario J. Goglia, Jack M. Spurlock, and Tommy L. Gossage, Performance of a JP-4 Aircraft Fuel System--A Comparison of Analytical Predictions with Experimental Results for Two-Phase Flow, WADC Technical Report 55-422, Part 3, Contract No. AF 33(616)-2660, Wright Air Development Center, Dayton, Ohio, March 1957.

14. Levy, Salomon, Theory of Pressure Drop and Heat Transfer for Two-Phase Two-Component Annular Flow in Pipes, Unpublished Master's Thesis, University of California, 1951.